JANUARY 1947

JOURNAL OF THE IRON AND STEEL INSTITUTE

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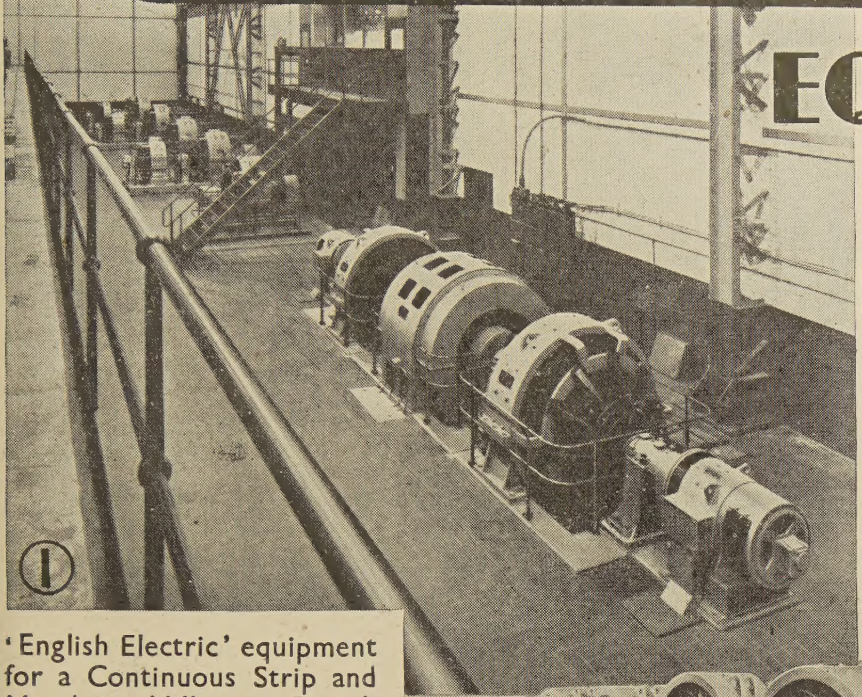

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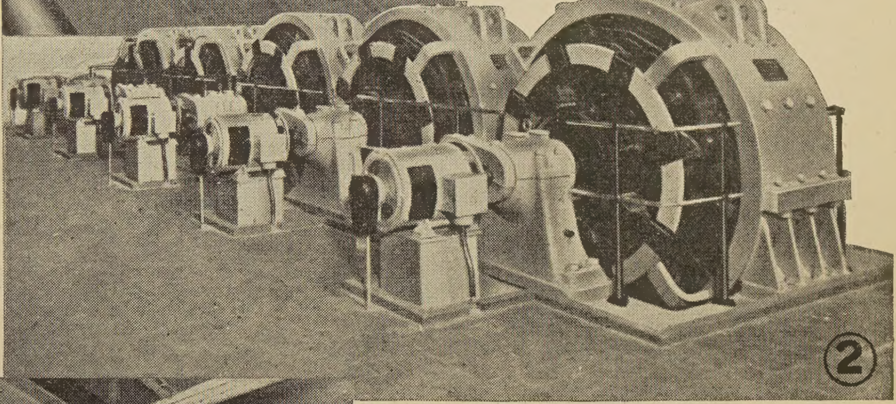

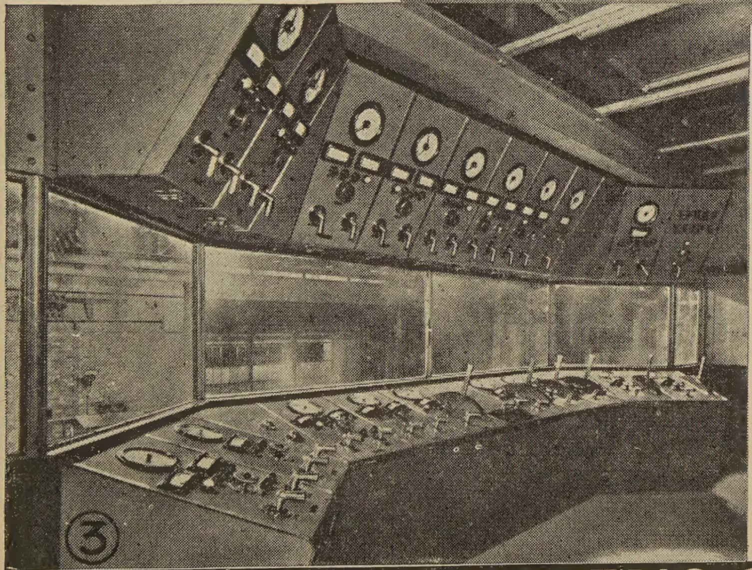

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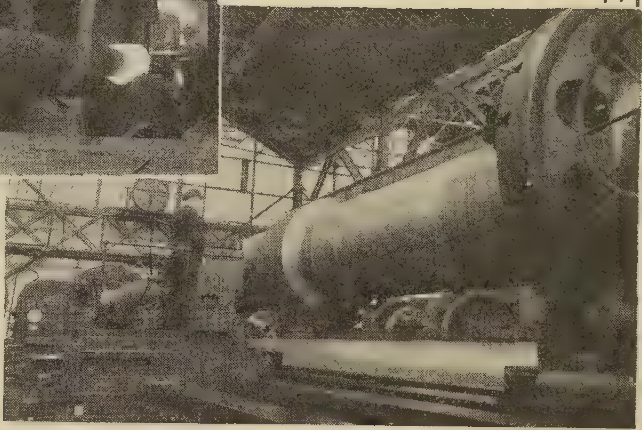

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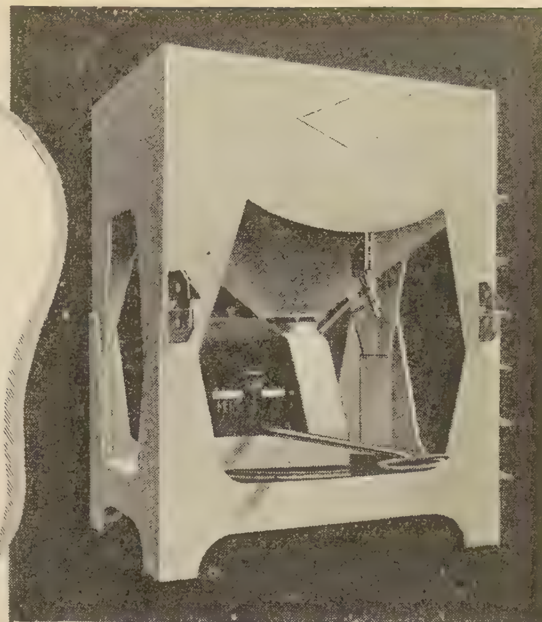

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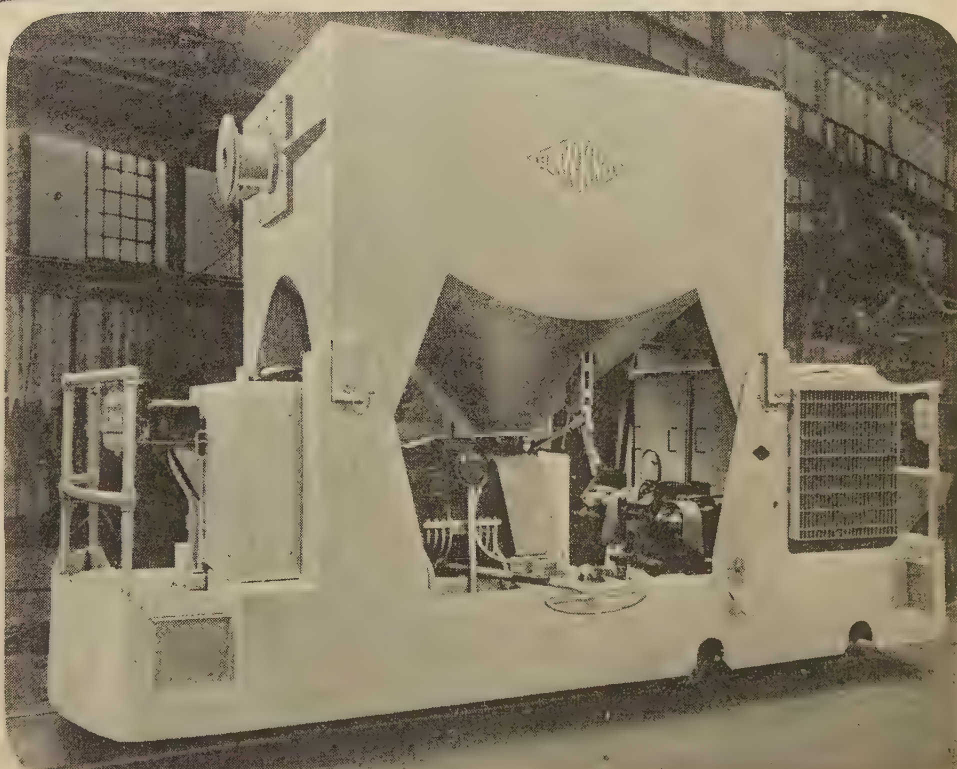

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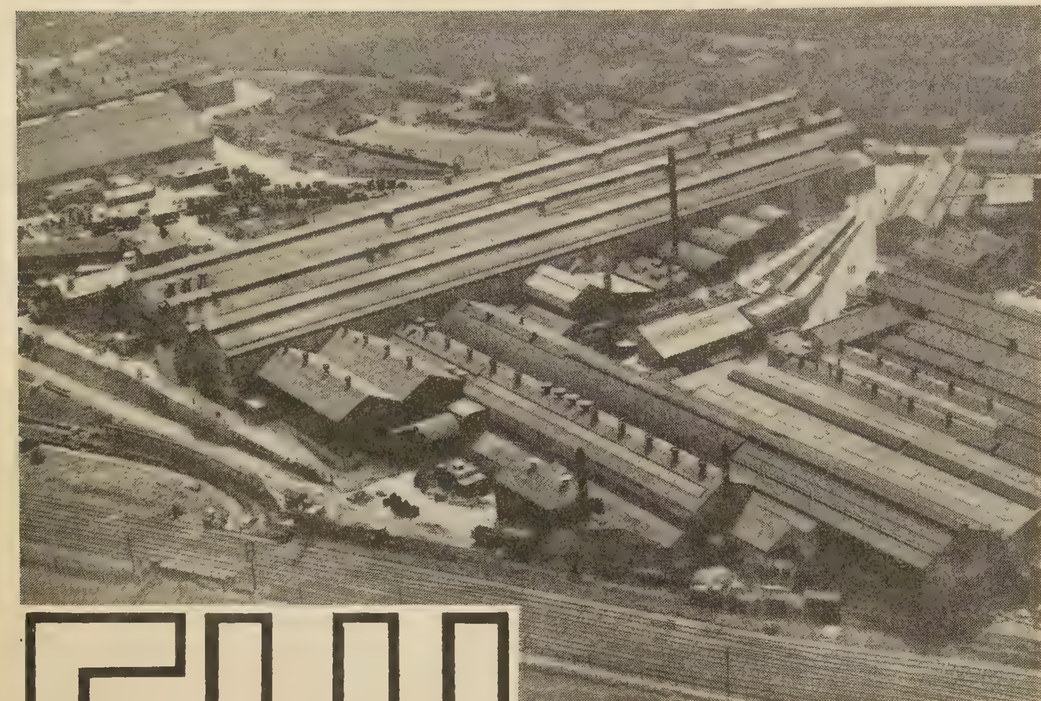

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THE PRESIDENT

1946 - 1947

C. H. Desch, D.Sc., Ph.D., LL.D., F.R.S.

PRESIDENT for 1946-1947, Dr. Cecil Henry Desch has agreed to accept nomination as President for a second year of office. The Institute will therefore have the benefit of his rich and varied metallurgical experience and knowledge for another year.

Born in 1874, in London, Dr. Desch was educated at Birkbeck School, Kingsland; Finsbury Technical College; University College London, and Würzburg University. He joined the metallurgical department of King's College, London, in 1902, and then took up an appointment as lecturer in Metallurgical Chemistry at Glasgow University, where he remained from 1909 until the end of World War I. For the next two years he was Professor of Metallurgy at the Royal Technical College, Glasgow, and on the death of Dr. J. O. Arnold he succeeded to the Chair of Metallurgy at Sheffield University in 1920.

A visit was made at the end of 1931 to the United States of America, where he was the George Fisher Baker Lecturer at Cornell University.

In 1932 Dr. Desch was appointed to succeed the late Dr. W. Rosenhain as Superintendent of the Department of Metallurgy of the National Physical Laboratory, Teddington, and he retired at the end of 1939.

In more recent years his technical abilities have been utilized more directly in industry. In 1943 Dr. Desch was appointed to the Board of Directors of Messrs. Richard Thomas and Company, Ltd., with the purpose of directing the research and development activities of that organization. With the amalgamation of the company with Messrs. Baldwins Ltd., in 1941, he resigned his directorship and has since been associated with the Whitehead Iron and Steel Co., Ltd.

In the academic field Dr. Desch has received wide recognition. He was elected a Fellow of the Royal Society in 1923, and was President of the Faraday Society from 1926 to 1928. His membership of the Iron and Steel Institute dates from 1913, and in 1938 he was awarded the Bessemer Gold Medal for his work in the advancement of metallurgy. He was also awarded, in 1941, the Platinum Medal of the Institute of Metals, of which he was President from 1938 to 1940.

Dr. Desch's renown is due in large measure to his many important books and papers on metallurgical and chemical subjects. Amongst the most familiar may be mentioned his "Metallography," "Intermetallic Compounds," and "Chemistry of Solids," the last being based on his Cornell University Lectures. A memoir on "Substitute Materials in War and Peace" is balanced by publications on ancient metallurgy which include a series of nine reports to the British Association on the source of the metals used by the Sumerians and other ancient peoples.

His activities also extend to Sociology and, as a member of the Institute of Sociology, he has presented a number of papers in this field, including a booklet on "Science and the Social Order."

Dr. C. H. Desch, F.R.S., President of the Iron and Steel Institute

A Message from the President

THE coming year should be an eventful one in the history of the Institute. Although the difficulties of the war will not have been completely removed—there will be for some time a shortage of paper and of printing labour—the new format of the Journal will make possible a better presentation of technical papers calling for illustration, and efforts will be made to develop new aspects of the Institute's work, in the educational field and elsewhere. The release of scientific and industrial developments which were necessarily kept secret during the war will probably mean an increase in the number of communications submitted for publication.

In the last year it has been possible to make contact with colleagues in several European countries and with visitors from the Dominions, India, America and other countries overseas. These valuable contacts will be further extended during the coming year, and the international character of the Institute will be notably reinforced by the decision to hold a summer meeting in Switzerland, where interesting technical developments have taken place in recent years.

The reconstruction of the iron and steel industry, whatever the form of its future organisation, will call for much thought on the part of its technicians, and the advancement of the scientific foundations of metallurgy will demand close attention. It is one of our main functions to make known to the body of our members the results of investigations carried out by the British Iron and Steel Research Association and by individuals, and we have also to interpret those results for members less familiar with the language of the laboratory.

That the next few years will be a period of expansion in the industry is certain ; an expansion only limited at present by the supply of raw materials. At the same time, to keep abreast of new demands needs continual attention to scientific progress. There is thus every reason to look forward to an increased activity in production and also in scientific research, to which it is our desire that the Institute, through its meetings, publications and special committees, shall contribute fully.

C. H. Desch.

THE JOURNAL

THE Journal of the Iron and Steel Institute was first published in 1869. The method of publication was, at the beginning, somewhat irregular. During the first two years, transactions were issued from time to time ; later, proceedings and papers were collected in a quarterly journal, which was normally bound into an annual volume. From 1887 to 1945, however, a regular sequence of publication was maintained. Two volumes appeared each year, although occasionally an extra volume has been issued. These books are all in octavo size and form the well-known series which occupies so prominent a position on the shelves of metallurgical libraries.

Only five editors have been responsible for the Journal ; the first Secretary, Mr. John E. Jones (1869 to 1877), and his successors, Mr. J. Stephen Jeans (1877 to 1893), Mr. Bennet H. Brough (1893 to 1908), and Mr. George C. Lloyd (1909 to 1933), who was followed by the present Secretary, Mr. K. Headlam-Morley in 1933. In 1940 Mr. Alan E. Chattin, who had been appointed Assistant Secretary fifteen years before, became also Assistant Editor and was later appointed Executive Editor. The Journal has owed much during the last twenty years to Mr. Chattin's knowledge and indefatigable care, and the Publication Committee are pleased that the Institute will continue to benefit by his experience as Technical Editor.

In 1939 the Council decided that the time had come to make a change. The war intervened and it was not until 1946 that the present size of page could be adopted ; this will in future be standard for the technical publications of the Institute.

Many will view with regret the end of the series of octavo volumes which, with their accompanying advance copies, fitted so conveniently into pockets and bookshelves, but the reasons are compelling. Apart from financial considerations the amount of material for which space has to be found, and the need to present diagrams and illustrations more clearly, make it necessary to use a larger page. 1946 was a year of transition during which papers were issued each month as advance copies. These will be bound up into two volumes, No. CLIII and No. CLIV. With the present issue the new series begins.

The Journal will in future be published monthly, and the contents, with the exception of advertisements, will be bound into three volumes each year ; those for 1947 will be numbered 155 to 157. Indexes and binding cases for each of the three periods, January to April, May to August, and September to December, will be supplied free of charge to Members and subscribers, and it will be possible also to buy bound volumes.

Each monthly part will normally contain about 150 pages of text with a moderate number of technical advertisements. The text will be divided into sections. Each month there will be sections devoted to Papers of the Iron and Steel Institute ; Reports and Papers submitted by the British Iron and Steel Research Association ; the activities of the Iron and Steel Engineers Group ; News ; and Abstracts and Book Reviews. From time to time other sections will be included ; for example, proceedings of the Institute and discussions on papers and reports may be expected at frequent intervals. The Council hopes that in the course of time correspondence on ferrous metallurgy and matters of technical interest will become a regular feature.

The value of the Journal to Members, metallurgists and those connected with the technical and scientific development of the iron and steel industries must depend in the future, as in the past, on the quality of its contents. The fact that the Journal has been adopted by the British Iron and Steel Research Association as the normal vehicle for publishing its work is in itself a guarantee that the contents will attain a high level of scientific and technical interest. Reports and papers intended for publication in this section and in that devoted to papers of the Iron and Steel Institute will only be accepted if, in the opinion of the Council, they are of sufficient merit ; and the Council and its Publication Committee will continue to avail themselves of the services of referees, a system which has worked very well in the past.

The inclusion each month of a section on iron and steel works engineering should increase the value of the Journal to those who are primarily concerned with design and maintenance. In this section there will be printed papers read at meetings of the Group, the discussions on these papers, and authoritative descriptions of new plants. It will be a function of the Engineering Committee to advise the Council on the contents.

Such merit as may be found in the production and appearance of the Journal is due to the skill and hard work of the editorial staff. The Council is pleased to have this opportunity of expressing appreciation of their services. The Council hopes also that with their help and with the encouragement of Members it will prove possible, when present restrictions are removed, to make this Journal of even greater value to the industry and Institute than the series which has now come to an end.

By order of the Council.

IRON AND STEEL
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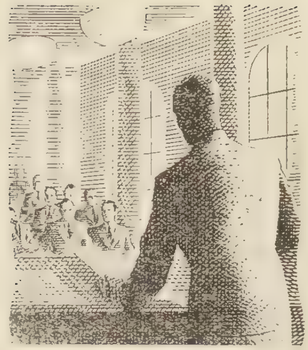

The Operation of Open-Hearth Furnaces with Coke-oven Gas*

By D. Kilby†

Synopsis

The paper deals with the operation of 100-ton basic open-hearth furnaces at the Redbourn Works of Messrs. Richard Thomas and Baldwins, Ltd., Scunthorpe, which are fired with coke-oven gas and pitch–creosote. Details of design and construction of furnaces, layout of the pitch–creosote main, design of gas burner and atomizers, operation of furnace, and chief factors affecting smooth working are presented. Typical charges, refractory consumption, a log of a furnace campaign with tonnage of ingots produced, and fuel consumption for a similar period are mentioned. Details of pitch–creosote are also given.

Introduction

The question of the method of firing of open-hearth furnaces is a complex problem indeed, conditions affecting the problem vary from plant to plant. Wide divergencies of opinion are held as to the most economic and technically suitable units on the steelworks to consume the surplus blast-furnace and coke-oven gas. Consideration must also be given to the type of fuel which is to be used to compensate for any deficiency in blast-furnace or coke-oven gas to maintain the fuel balance. The author feels that the straight coke-oven-gas-plus-illuminant method of firing is deserving of greater consideration under today's conditions, particularly so because of the flexibility of the fuel mixtures which can be used, increased tendency to use fuel oil, and simplicity of furnace layout.

Much of the early work in connection with the firing of open-hearth-steel furnaces with coke-oven gas was carried out in Germany. The necessity to consume large quantities of available coke-oven gas from the Ruhr gas system no doubt had a stimulating effect on this. Eventually, when a successful method of firing had been established, a preponderance of open-hearth plants changed over to this type of fuel as indicated by Weseman [1] in an analysis of types of fuel used in 50 German steelworks :

15 plants used coke-oven gas.
8 plants used brown-coal-briquette gas.
10 plants used producer gas.
10 plants used Dreigas.
7 plants used mixed blast-furnace and coke-oven gas.

This would suggest that both economically and from the technical aspect this method of firing had much to recommend itself, and was particularly suited to the conditions prevailing in Germany.

Cold coke-oven gas with or without an illuminant does not appear to have achieved any degree of popularity as an open-hearth furnace

* Received 20th May, 1946.

† Messrs Richard Thomas and Baldwins, Ltd., Redbourn Works, Scunthorpe, Lincs.

fuel in Great Britain. To the author's knowledge only three or four works use this method of firing, most of the integrated steelworks use mixed blast-furnace and coke-oven gas, or producer gas to a lesser extent.

As an operator of open-hearth furnaces fired with cold coke-oven gas/pitch–creosote, the author would like to give some details affecting design and practical operational difficulties that are associated with this type of furnace, with particular reference to 100-ton fixed furnaces, as operated at Messrs. Richard Thomas and Baldwins, Ltd., Redbourn Works.

In the Redbourn Works' melting-shop there are three 100-ton producer-gas-fired furnaces operating under identical conditions as three 100-ton coke-oven-gas/pitch–creosote-fired furnaces. Pitch–creosote has been used for the last six years as an illuminant on the coke-oven gas furnaces, before which tar was used.

Factors Governing Furnace Design

(*a*) A sufficiently high flame temperature for the performance of the open-hearth process is achieved without preheating the coke-oven gas, only air being preheated.

(*b*) A larger volume of air to be preheated is required than that required for a producer-gas-fired furnace of a similar capacity.

(*c*) Necessity to supply an illuminant, particularly when high percentages of hot metal are worked, if efficient heat transfer is to be achieved ; although if coke-oven gas is cheap, the economics may be such that it is cheaper to avoid the use of an illuminant and use a greater amount of coke-oven gas though the B.Th.U. consumed per ton of steel will be higher.

The most important departures from the conventional design of open-hearth furnaces are :

(i) The entire products of combustion are used for heating the regenerators for preheating the air only, the coke-oven gas being used cold. By doing this the need to reduce the gas-port size to obtain good gas velocity and flame direction is not compromised by the amount of the products of combustion which are required to pass through the gas port as in the producer-gas-fired or mixed-gas-fired furnace, but is governed by the quantity of fuel to be delivered to the furnace. This control of gas-port size is very desirable if the speed of working is to be maintained at a maximum, and full use is to be made of the heat input.

(ii) For a furnace of a given size the amount of air required for combustion in a coke-oven-gas-fired open-hearth furnace is approximately $1\frac{1}{4}$–$1\frac{1}{2}$ times that needed for a producer-gas-fired furnace of a similar size. Also, the total volume of the products of combustion from both types of furnace is approximately the same, therefore, although the gas is not regenerated, if comparable results are to be attained both in fuel consumption and life of regenerator brickwork the total regenerator capacity of the coke-oven-gas-fired furnace must be at least equal to the combined gas and air regenerator capacity of the producer-gas furnace. In the interest of efficient combustion, and to ensure reasonable regenerator life, it is necessary to use air supplied by a fan.

(iii) The introduction of an illuminant into the furnace ends calls for some modification of port-end design if the method of injection is to work smoothly ; also, auxiliary plant must be available to supply a constant feed of pitch–creosote mixture or other illuminant at the required temperature and pressure at both ends of the furnace, together with the requisite amount of steam for atomization.

Description of 100-ton Furnace

Built on 100-ft. centres, the furnaces are housed in a building measuring 875 ft. × 130 ft. Serving the furnaces are three magnet cranes and three charging machines of the low ground type. Metal is transferred to the furnaces by 100-ton overhead cranes, two of which are available in the furnace bay. The casting bay is served by three 150-ton overhead cranes which transfer the steel to be cast either in moulds on bogies, or in pits if bottom pouring is specified.

Figure 1 is of a furnace now under construction. It will be noticed that this furnace has been fitted with auxiliary dampers which it is hoped will eliminate completely the trouble experienced with unbalanced regenerator temperatures, about which more will be said later. Table I gives the various dimensions, &c., of the three coke-oven-gas-fired furnaces working at the moment and the one under construction.

The first furnace adapted for the firing of straight coke-oven gas was converted from a 60-ton fixed producer-gas-fired unit. To accommodate the change in the type of fuel, changes were made to the furnace, the chief of which were the elimination of the gas reversing valve and the joining together of the gas and air flues into one common flue, the installation of a straight-through type Blaw Knox air reversing valve, and the redesigning of the port ends. Later a further two furnaces were built to burn coke-oven gas, and at the moment another coke-oven-gas-fired furnace is under construction.

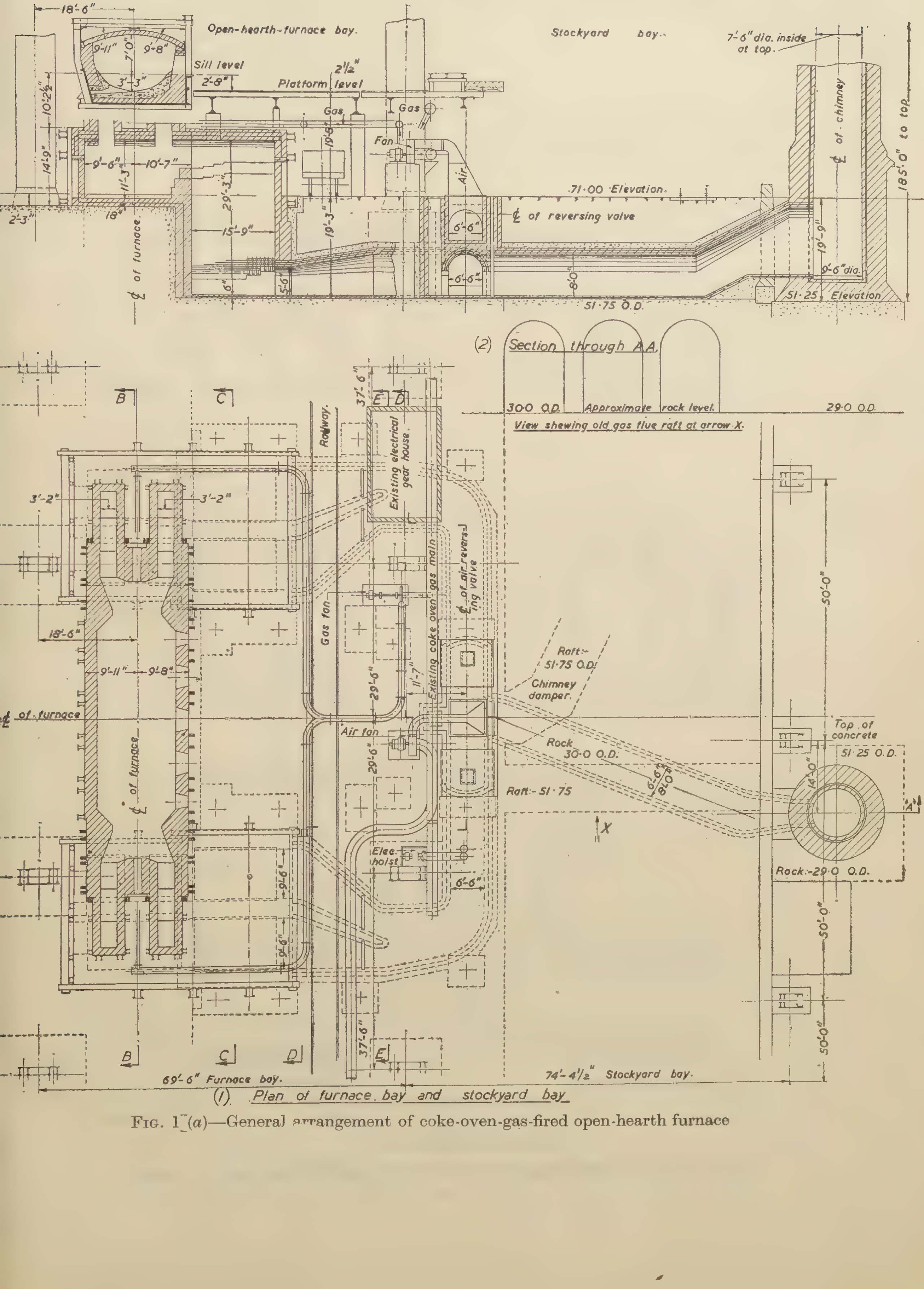

FIG. 1 (a)—General arrangement of coke-oven-gas-fired open-hearth furnace

With slight variations, a description of the last furnace built is representative of the general arrangement and construction of all the coke-oven-gas-fired furnaces.

Furnace Body

The furnace body is supported by two concrete pillars protected by a covering of brickwork. Between these two pillars is laid a railroad, upon which is placed the slag carriage and slag pan, to be pulled into position under the slag notch by the teeming crane. Across the pillars are laid 18 in. × 8 in. joists to support the bath of the furnace. Castings and cast-iron plates are used to form the pan of the furnace hearth. Steel slabs, 13½ in. × 5 in., are used for the buckstaves on the charging side of the furnace. A semi-sloping back wall having a slope of 15°, supported by buckstaves each built up with two 15-in. × 4-in. channels, bent, welded, and plated is

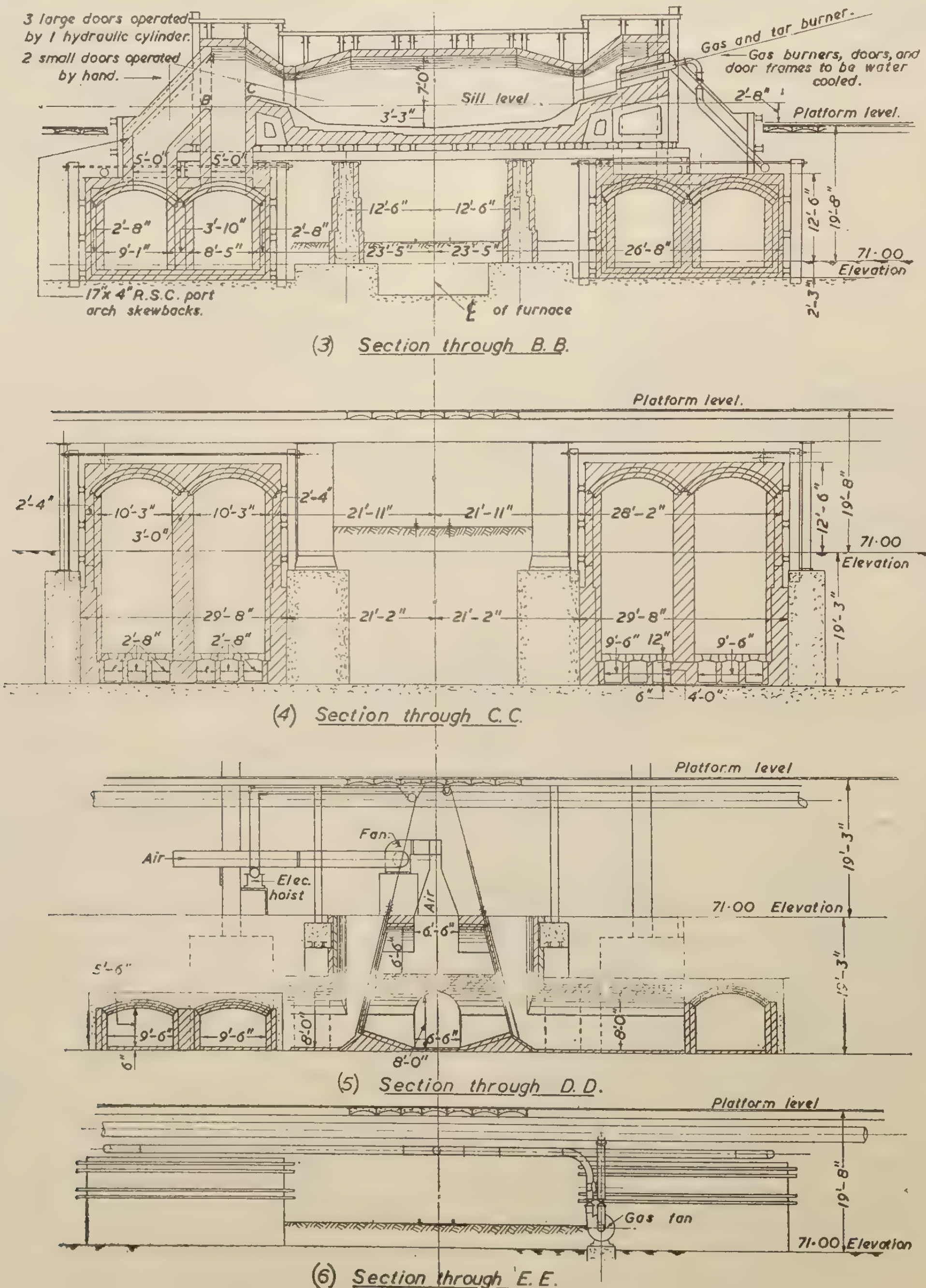

Fig. 1 (b)—General arrangement of coke-oven-gas-fired open-hearth furnace

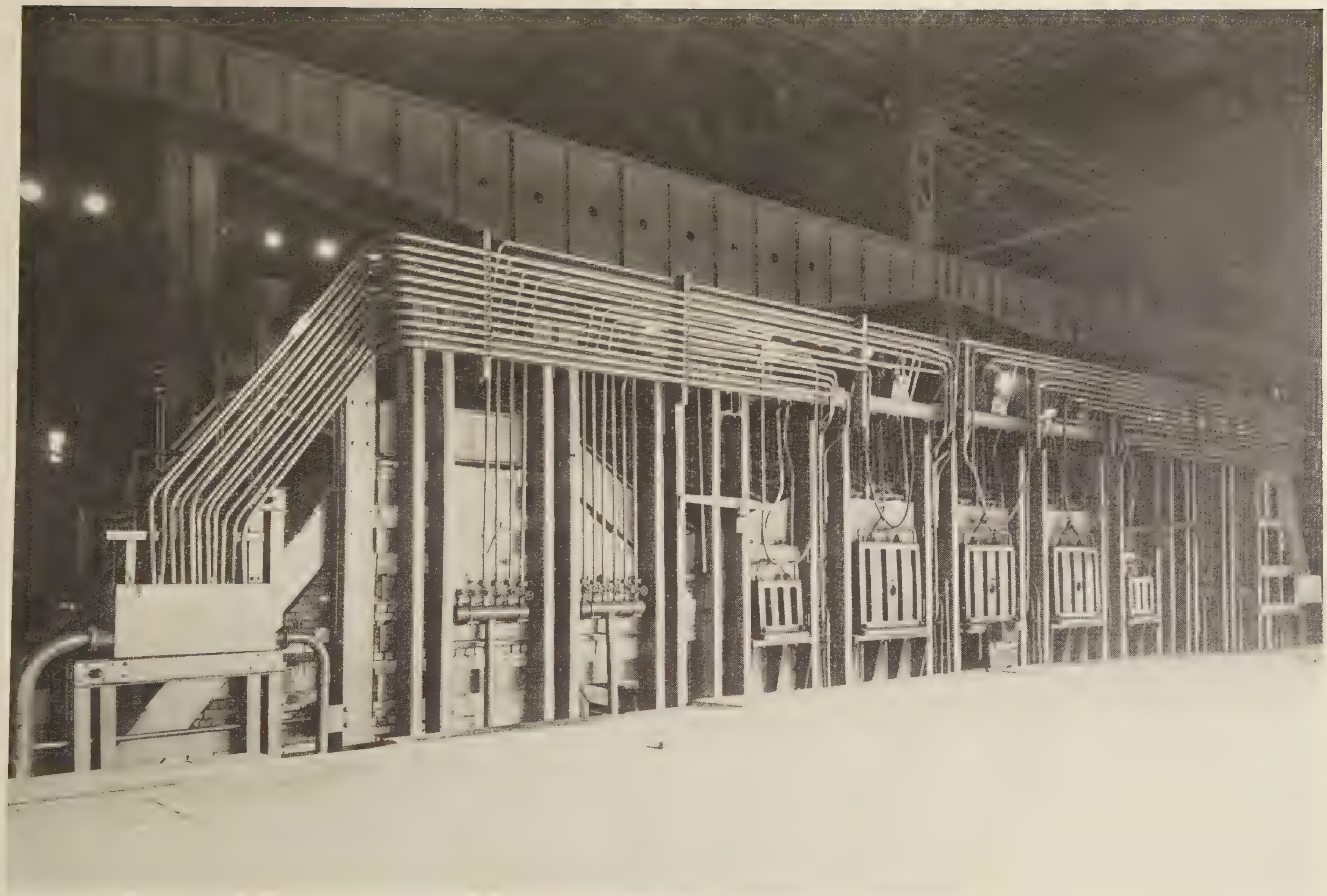

FIG. 2—View of 100-ton open-hearth furnace from the working platform

incorporated. Water-cooled lintels and jambs are fitted, but dry cast-iron doors are at present used, due to shortage of cooling water. The charging doors are three in number, measuring 3 ft. 9 in. × 3 ft. 9 in., the centre door being fitted with a slag notch. Two small fettling doors are also provided, as illustrated in Fig. 2. A catwalk has been built along the centre of the furnace bracings for the purpose of roof inspection and repairs.

Hearth

Insulation of the hearth up to sill level is accomplished by the use of asbestos board ½ in. thick. A course of Scotch firebrick is laid on the asbestos board, apart from a section measuring 12 ft. × 8 ft. in front of the tap-hole which is all magnesite from the asbestos board to the final covering of stabilized dolomite brick. After shaping up the ends and breasts with firebrick, sufficient magnesite bricks are laid to give a minimum thickness of 9 in. of magnesite in all parts of the hearth. A covering of stabilized dolomite brick, 3 in. thick, is then placed on the magnesite (in future magnesite will be used for this course). As each course is laid it is well bedded with dry magnesite powder, and a surplus amount is brushed over the bricks to make certain all small cavities are filled. Approximately ⅛ in. of dry magnesite powder is used as bedding between courses. For expansion a space of 2 in. is allowed round the hearth, which is filled with sawdust; also ¼-in. thick expansion joints in each course are placed at intervals of 3 ft. Having completed the bricking of the hearth, fires in braziers are placed on the hearth to dry and warm it. These fires are then withdrawn and gas flares are placed in position and ignited. Twenty-four hours later the furnace is gassed and brought up to fettling temperature. Nine to twelve inches of dolomite are then burnt in on the hearth bricks.

A graphitized dolomite hearth on firebricks has recently been installed, and so far results are very satisfactory. Ultimate policy in regard to the hearth may develop on these lines.

Roof

A plain roof 12 in. thick is installed having a span of either 17 ft. or 18 ft. 6 in., depending whether the back lining is straight or semi-sloping. The centre of the roof is 7 ft. above the sill-plate level, and 2 ft. 3 in. above the knuckle. The tap-hole side of the roof is 6 in. higher than at the charging side of the furnace.

Front and Back Linings

Chrome–magnesite bricks are used for the back lining and for the pillars of the front lining, the arches being silica. Both linings are 18 in. thick.

Ports

The port ends are of the Venturi type, the area at the throat of the furnace being 37 sq. ft. The

TABLE I—*Furnace Data, &c.*

	C Furnace.	*E* Furnace.	*F* Furnace.	*G* Furnace Now Building.
Length of bath	40 ft. 0 in.	40 ft. 0 in.	40 ft. 0 in.	40 ft. 0 in.
Width of bath	13 ft. 6 in.	13 ft. 6 in.	13 ft. 6 in.	13 ft. 6 in.
Cross-sectional area of laboratory above sill at C/L.	97½ sq. ft.	90 sq. ft.	90 sq. ft.	97½ sq. ft.
Area at knuckle ...	37 sq. ft.	37 sq. ft.	37 sq. ft.	37 sq. ft.
Size of opening at bridge wall	4 ft. 6 in. × 7 ft. 0 in. 4 ft. 6 in. × 6 ft. 3 in.	4 ft. 6 in. × 7 ft. 0 in. 4 ft. 6 in. × 6 ft. 3 in.	4 ft. 6 in. × 7 ft. 9 in. 4 ft. 6 in. × 6 ft. 3 in.	5 ft. 3 in. × 9 ft. 1 in. 5 ft. 3 in. × 8 ft. 5 in.
Size of valve opening ...	6 ft. 0 in. × 6 ft. 6 in.	...	6 ft. 6 in. × 6 ft. 6 in.	6 ft. 6 in. × 6 ft. 6 in.
Type of valve	Blaw Knox	Butterfly	Blaw Knox	Blaw Knox.
Stack flue	6 ft. 6 in. × 8 ft. 0 in.	6 ft. 6 in. × 8 ft. 0 in.	6 ft. 6 in. × 8 ft. 0 in.	6 ft. 6 in. × 8 ft. 0 in.
Stack:				
Height	185 ft.	185 ft.	185 ft.	185 ft.
Dia. at base	9 ft. 6 in.	9 ft. 6 in.	9 ft. 6 in.	9 ft. 6 in.
Dia. at top	7 ft. 6 in.	7 ft. 6 in.	7 ft. 6 in.	7 ft. 6 in.
Overall length of roof ...	67 ft. 2 in.	67 ft. 2 in.	67 ft. 2 in.	67 ft. 2 in.
Span of main roof ...	18 ft. 6 in.	17 ft. 0 in.	17 ft. 0 in.	18 ft. 6 in.
Length of long ramps...	8 ft. 0 in.	8 ft. 0 in.	8 ft. 0 in.	8 ft. 0 in.
Length of short ramps...	5 ft. 9 in.	5 ft. 9 in.	5 ft. 9 in.	5 ft. 9 in.
Slope of long ramps ...	2 ft. 3 in. in 8 ft. 0 in.	2 ft. 3 in. in 8 ft. 0 in.	2 ft. 3 in. in 8 ft. 0 in.	2 ft. 3 in. in 8 ft. 0 in.
Slope of short ramps ...	4 ft. 0 in. in 5 ft. 6 in.	4 ft. 0 in. in 5 ft. 6 in.	4 ft. 0 in. in 5 ft. 6 in.	4 ft. 0 in. in 5 ft. 6 in.
Length of roof ...	40 ft.	40 ft.	40 ft.	40 ft.
Rise in roof	1 ft. 9 in.	1 ft. 9 in.	1 ft. 9 in.	1 ft. 9 in.
Knuckle centres ...	42 ft.	42 ft.	42 ft.	42 ft.
Height of roof over sill level	7 ft. 0 in.	7 ft. 0 in.	7 ft. 0 in.	7 ft. 0 in.
Size of slag pockets	14 ft. 0 in. × 6 ft. 3 in. × 5 ft. 0 in. 14 ft. 0 in. × 7 ft. 0 in. × 5 ft. 0 in.	14 ft. 0 in. × 6 ft. 3 in. × 5 ft. 0 in. 14 ft. 0 in. × 6 ft. 3 in. × 5 ft. 0 in.	14 ft. 0 in. × 6 ft. 3 in. × 5 ft. 0 in. 14 ft. 0 in. × 7 ft. 9 in. × 5 ft. 0 in.	17 ft. 6 in. × 6 ft. 0 in. × 9 ft. 1 in. 17 ft. 6 in. × 6 ft. 0 in. × 8 ft. 5 in.
Size of regenerator chambers	10·9 ft. × 17 ft. × 25 ft. 7·0 ft. × 17 ft. × 25 ft.	10·9 ft. × 17 ft. × 25 ft. 7·0 ft. × 17 ft. × 25 ft.	10·9 ft. × 21 ft. × 25 ft. 7·0 ft. × 21 ft. × 25 ft.	10·3 ft. × 15·9 ft. × 29·3 ft. 10 3 ft. × 15·9 ft. × 29·3 ft.
Total volume of regenerator bricks at each end	4828 cu. ft.	4828 cu. ft.	5964 cu. ft.	5166 cu. ft.
No. of courses	41–42	41–42	41–42	41–42
Volume of regenerator chambers at each end	7306 cu. ft.	7306 cu. ft.	9031 cu. ft.	9052 cu. ft.
Type of back wall ...	Semi-sloping	Straight	Straight	Semi-sloping.

wing walls forming the throat of the furnace are built of chrome–magnesite at the bath side and silica at the port-end side. Built into the end wall is a water-cooled jacket (Fig. 3), through which the combined gas-and-pitch–creosote burner is placed. This water-cooled jacket acts as a support from which the arches supporting the end wall are sprung. Covering the water-cooled jacket are $13\frac{1}{2}$ in. of silica, to within 27 in. of the nose of the cooler; the remainder of the refractory covering is chrome–magnesite, which projects 9 in. beyond the nose of the cooler. A slope of 1 in 4 is given to the cooler jacket, and the burner is set at an angle of 14°. A distance of 5 ft. separates the centre-line of the knuckle and the burner end. Magnesite bricks are used for the paving of the port.

Uptakes

Four uptakes at each end of the furnace lead from the slag pockets to the port. The uptakes have a total area of 54 sq. ft. and are built with silica.

Slag Pockets

The slag pockets at each end of the furnace have a cubic capacity of 927 cu. ft. A loose course of old silica brick is placed round the inside wall of the pockets, to protect the wall and facilitate the removal of the slag.

Regenerators

Regenerator capacity at each end of the furnace is 4,828 cu. ft. The regenerator chamber roofs are built of best quality firebrick, and give no trouble. Checker bricks 9 in. × $4\frac{1}{2}$ in. × 3 in. are used, and are so placed to give a straight-through opening of 6 in. × 6 in. Forty-one courses of checkers are laid, the top ten courses are of silica, the remainder are of firebrick.

Flues

The flues for both regenerators at each end of the furnace converge into one flue leading to the air reversing valve. This is a straight-through type valve, having an opening of 6 ft. × 6 ft. 6 in.

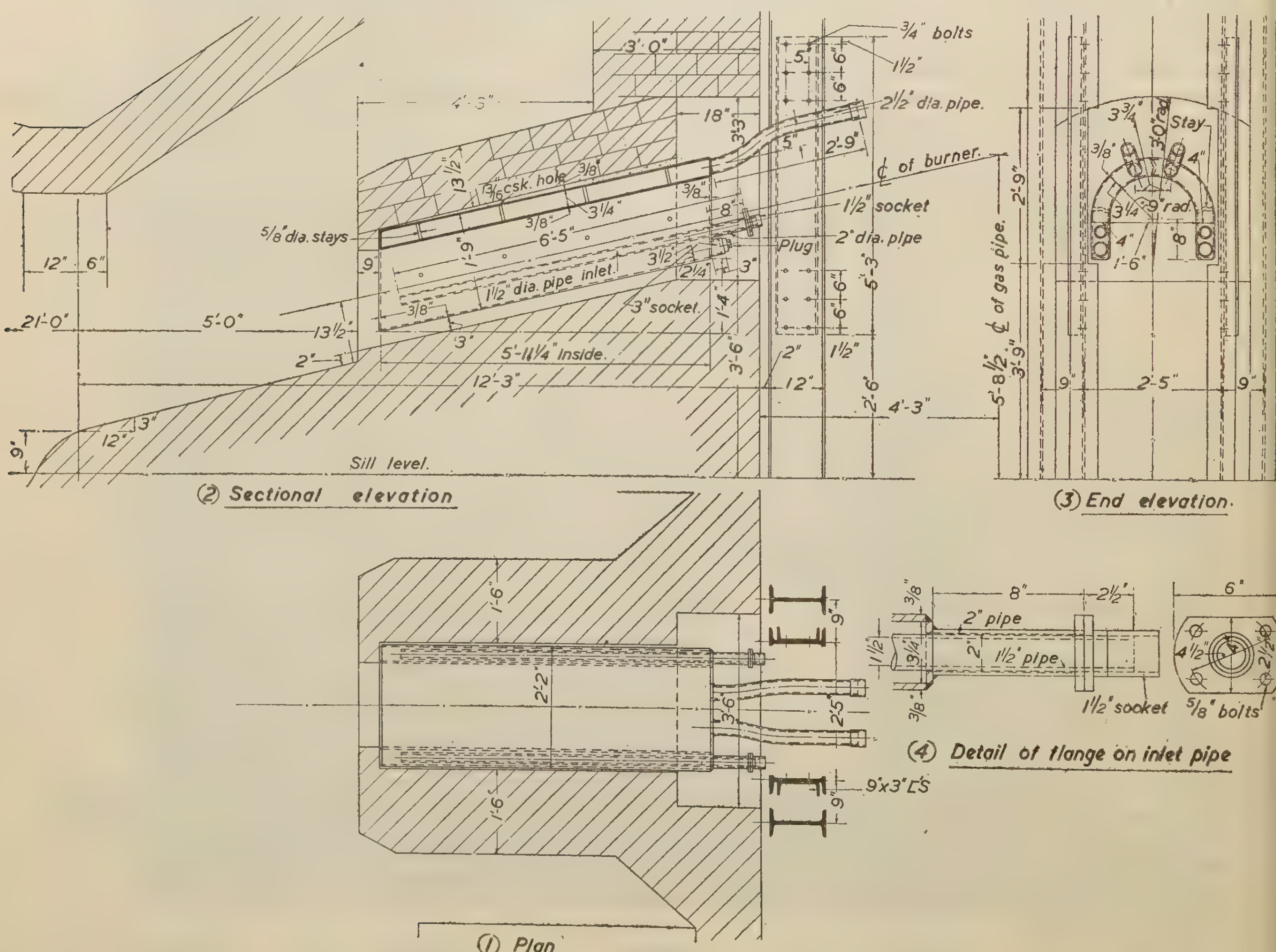

FIG. 3—Arrangement of water-cooled jacket at end of furnace

Originally the air valve was water cooled, but now the water cooling has been eliminated and cast-iron parts are used, which have been found entirely satisfactory. The stack flue measures 8 ft. × 6 ft. 6 in., leading to a stack 185 ft. in height, and a mean inside diameter of 8 ft. 6 in.

Combined Gas-and-Pitch Burner

The combined gas-and-pitch–creosote burner (Fig. 4) is suspended from the furnace-end structure by means of a steel strap attached to a screwed steel bar, which allows the burner to be either raised or lowered, whichever may be desired. Fitted to the goose-neck pipe connecting the burner to the gas main is a ball joint, which allows lateral movement. In construction the gas burner consists of a water-cooled cylindrical jacket made from 12-in. seamless steel tube, through which pass the pitch–creosote tube and the gas tube. The inlet pipe for the cooling-water supply is brought to the nose of the burner to ensure efficient cooling and good burner life. The gas tube is 6 in. in diameter, reducing to $3\frac{1}{2}$ in. at the exit end to give greater velocity to the gas. The conical portion of the gas tube is machined to size to give a good and accurate finish. A tube of 1-in. dia. is used for the delivery of the pitch from the atomizer through the burner to the furnace. This pitch tube is reduced to $\frac{11}{16}$ in. at the exit end. A gland is fitted between the pitch tube and the rear end of the burner casing which allows the pitch tube to expand and contract freely, preventing distortion of the tube, which would have an adverse effect on flame direction. An inspection cover is placed on the goose-neck connection in line with the gas tube for the removal of soot and deposit from the inside of the burner. Sooting-up of the burner occurs to a much greater extent when draughting is poor.

Atomization of the pitch–creosote mixture is accomplished by the use of steam. The atomizer (Fig. 4) is attached to the rear end of the pitch tube and is easily removable to facilitate cleaning of the pitch tube and atomizer. It is usual to have spares ready and it is a matter of minutes only to replace the old atomizer with a new one. The atomizer itself consists of a 1-in. tube 12 in. long, inside which is inserted a $\frac{1}{8}$-in. tube to carry the pitch–creosote from the supply pipe to the atomizer. This tube is held in a central position by the atomizer proper and a brass nipple. The pitch–creosote is emitted through the hole $\frac{7}{32}$ in. in dia. in the centre of the atomizer. Around this hole are eight holes $\frac{3}{16}$ in. in dia., placed equidistant and inclined towards the centre at an angle of 5°. Screwed on to the 1-in. pipe is a T-piece through which the steam is introduced to pass along the outside of the $\frac{1}{8}$-in. tube, and through the eight $\frac{3}{16}$-in. holes to atomize the pitch–creosote and convey it to the furnace. A small proportion of steam is left on the atomizer when the furnace has been reversed and the pitch-creosote has been shut off. This is to prevent sooting-up of the pitch tube.

Fuel

Heat input to the coke-oven-gas-fired furnaces varies from 33×10^6 to 42×10^6 B.Th.U./hr. Constituting this, 76–79% is derived from the coke-oven gas and the remainder from the pitch–creosote. At the moment of writing, trials are being made with increased quantities of pitch–creosote to compensate for a reduction in the quantity of coke-oven gas available to each furnace. Fuel mixtures with up to 40% of the heat input derived from the pitch–creosote have been worked.

Characteristics of the pitch–creosote are as tabulated below :

Specific gravity	1·20.
Calorific value	16,500 B.Th.U./lb.
Sulphur content	0·3–0·5%.
Viscosity (Redwood) :	
At 60° C.	2500 sec.
At 70° C.	1000 sec.
At 80° C.	500 sec.
At 100° C.	170 sec.
Evaporation range :	
Up to 200°	0·19 wt.-%.
200°–270° C. ...	12·1 wt.-%.
270°–300° C. ...	6·0 wt.-%.
Softening point of residue	40° C.

Analysis of coke oven gas :

H_2, %.	CH_4, %.	N_2, %.	CO, %.	C_xH_y, %.	$CO_2 + H_2S$, %.
52·3	28·0	4·8	7·6	3·5	3·8

Calorific value ... 540 B.Th.U./cu. ft.

The pitch–creosote conforms to Coal Tar Fuel 250. It will be noticed later in the paper that the pitch–creosote is atomized at a somewhat lower temperature than that recommended by the Technical Sub-Committee of the Association of Coal Tar Distillers.[2] A temperature of 115° C. is suggested for Coal Tar Fuel 250 by this Sub-Committee. At the present time with the plant available at the Redbourn Works it is impossible to operate at this higher temperature, but periods have been worked with the pitch–creosote at a temperature of 90° C., and the conclusion arrived at was that in cases where pitch–creosote is used only as an illuminant, especially in a long furnace such as an open-hearth furnace, the lower temperature atomization is quite effective and possesses a major advantage inasmuch as the effect of heating the pitch–creosote to a higher temperature is to improve atomization, and

correspondingly increase the speed of combustion of the pitch–creosote and produce a short flame, localizing the heat from the illuminant at the ingoing end of the furnace and defeating the object for which the illuminant was added.

Where the pitch–creosote constitutes more than say, 25% of the heat input, the possibility of losing flame length due to combustion taking place too rapidly is very remote; it is, in fact, rather the opposite. This would suggest that

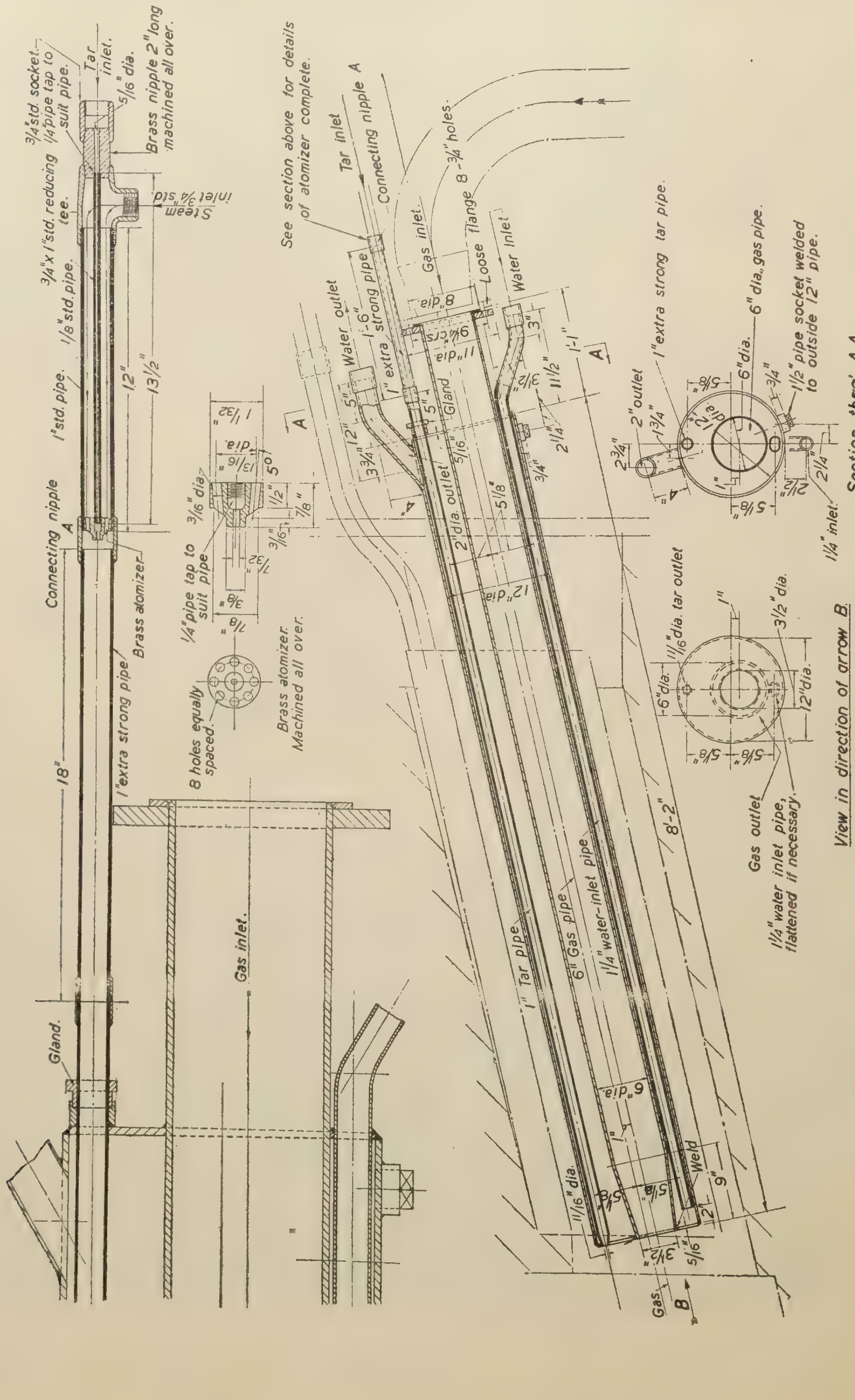

FIG. 4—Combined pitch–creosote and gas burner, and pitch–creosote atomizer

to help to control flame length and get the best combustion from various percentages of pitch–creosote (and still allow sufficient steam to be used to give good flame direction), the temperature of the pitch-creosote should be increased proportionately to the percentage used, up to a maximum temperature of 115° C. for Coal Tar Fuel 250. In other words the object should be (1), in cases where small percentages of illuminant are used, to retard the speed of combustion of the illuminant and extend the flame length by poorer atomization and thus make fuller use of the pitch–creosote as an illuminant, and (2) where large percentages of pitch–creosote are used, to improve atomization by operating with the pitch–creosote at the higher temperatures to guarantee complete combustion and maximum heat liberation within the laboratory of the furnace.

Layout of the Pitch–Creosote Plant and Main

The plant for storing and heating the pitch–creosote was originally installed to work with crude tar, in which case very little heat was necessary to maintain the tar in a good free-running condition. On converting to pitch–creosote extra steam coils were fitted into the storage tanks, and the fuel main was lagged together with a steam pipe of 2 in. dia.

Pitch–creosote is delivered to the storage tanks in railway tank-wagons fitted with steam coils. Only a proportion of the tank-wagons are lagged. Occasionally it is necessary to use steam to empty them in winter-time if a delay is experienced in transit from the tar refinery. The storage tanks are placed at such a level to allow the tank-wagons to be emptied by gravity. Storage capacity for approximately 80 tons is provided. Connections to the storage tanks are so arranged that the pitch–creosote is emptied into No. 1 tank and passes through the heater into No. 2 tank in which is placed the suction pipe from the pump. A proportion of the returns are allowed to flow back into each tank as illustrated in Fig. 5. The amount of steam delivered to the storage tanks is automatically regulated to maintain a temperature of 68°–72° C. in summer and 75°–78° C. in winter by a Drayton liquid-filled thermostat. A Mather and Platt centrifugal pump operating at 1450 r.p.m. by a 24-h.p. motor is used for circulating the pitch–creosote and is capable of delivering 85 gal./min. In cases of emergency a steam reciprocating pump is used. This pump is kept working slowly at all times. Both electric and steam pumps are situated on a platform on top of the storage tank ; they are so placed to allow any leakage of pitch–creosote from the pump glands to return to the storage tanks.

The centrifugal pump maintains a more constant pressure than does the reciprocating pump. The pulsating effect of the steam pump is reflected in the rather more variable flame length. When the steam pump is working, 10–15% more pitch–creosote is used than when the electric pump is in commission.

Pitch–creosote is circulated through a ring main to the end of each furnace, at a pressure of 85 lb./sq. in. The main is 4 in. in dia. reducing to 2 in. on the furnaces at each end of the shop. Approximately 95% of the pitch–creosote is returned to the storage tanks for re-circulation. A weight-loaded valve at the exit end of the return main serves as a governor. The pitch–creosote main is connected to both ends of all the producer-gas-fired furnaces, and is made use of occasionally should a furnace have difficulty in obtaining a normal supply of gas due to deterioration of gas regenerators or any other such circumstances that make it desirable to supplement the fuel input to maintain production on a slow-working furnace. When it is intended to make use of the pitch–creosote a small pitch burner is put in the stopping of the gas port, and the pitch–creosote and steam connections are made. Pitch–creosote has been used on the producer-gas units to supplement the fuel input due to shortage of gas coal at various times. When this has been done the B.Th.U. consumption per ton of steel increased 10–12%. Coke nuts have also been used on the gas producers at the same time.

Control of the supply of pitch–creosote to the

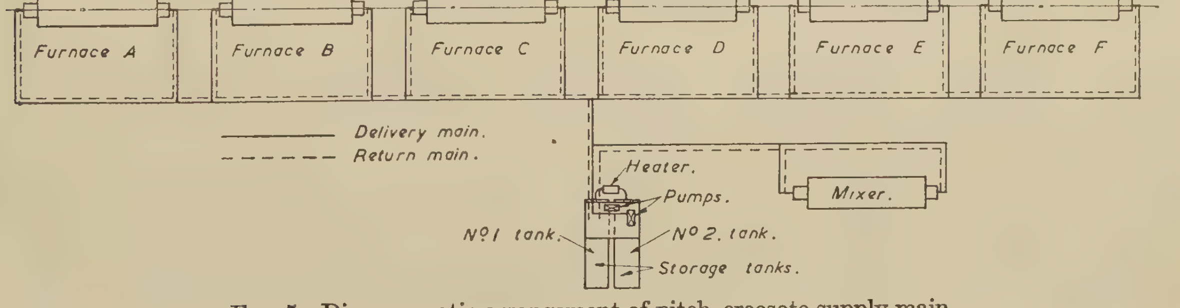

Fig. 5—Diagrammatic arrangement of pitch–creosote supply main

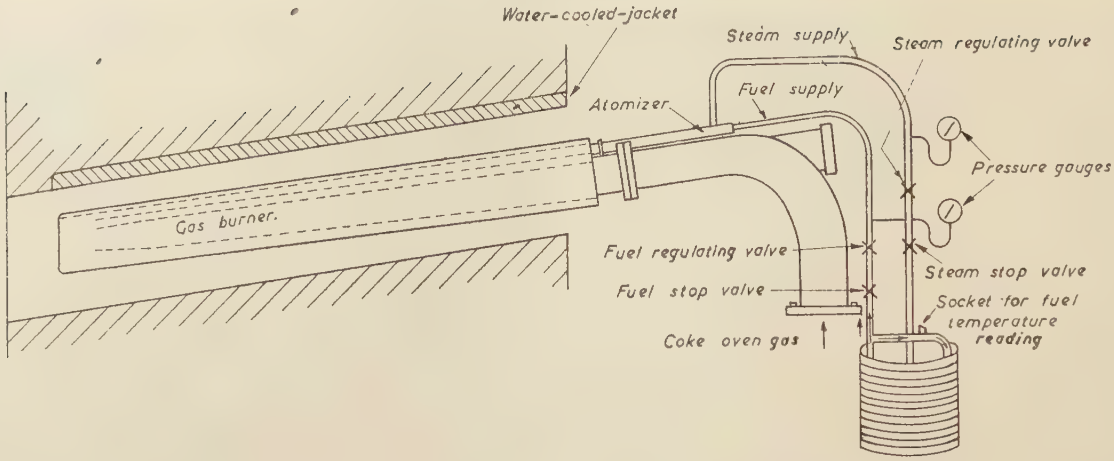

FIG. 6—Arrangement of pitch–creosote and steam supply at the furnace end

burner on each furnace is accomplished by two valves as shown in Fig. 6. One valve is adjusted to give the desired amount of pitch–creosote, the other acts as a stop valve. Pressure gauges are fitted to both steam and pitch–creosote supply pipes after the regulating valves ; these gauges give a relative guide as to the amount of steam and fuel being used. Naturally the pressures indicated are low, the steam is operated at 40 lb./sq. in. and the pitch at 30 lb./sq. in. The actual pressure in the steam main is 125 lb./sq. in., and, previously mentioned, 85 lb./sq. in. in the fuel main.

Gas and Air Supply

A 24-in. main from the coke-oven gas-holder supplies coke-oven gas at a pressure of 6–8 in. to the melting shop. Leading from this main to each furnace is a 12-in. main reducing to 8 in. at the gas valve. A No. 4 type Keith Blackman fan boosts gas to the furnace. The fan is constructed with a mild-steel impeller and forward-curved blades and mild-steel back-plates ; it is dynamically balanced, driven by a 25-h.p. variable-speed motor at a speed range of 1600–2300 r.p.m. and is capable of delivering up to 180,000 cu. ft. of gas per hour at a pressure of up to 22 in. W.G. A drain is fitted at the bottom of the fan case for the removal of condensate which occasionally collects there.

Air for combustion is supplied by a Keith Blackman centrifugal fan. The fan is fitted with a multivane impeller, driven by a 30-h.p. motor operating at 900–1200 r.p.m., and is capable of delivering up to 15,000 cu. ft./min. at 6 in. W.G.

Both air and gas are metered to the furnace by Arkon recorders of the floating inverted bell type, with a parabolic displacer to give an evenly graduated chart.

Steam for Atomization

Steam consumption for the atomization of the pitch–creosote is in the region of 120 lb. per ton of steel. This figure is rather high, due to the necessity of leaving a proportion of the steam on the atomizer when the pitch–creosote is turned off at each reversal, to prevent the atomizer becoming made-up with carbon.

The amount of steam consumed at the atomizer is influenced by the temperature of the pitch–creosote ; as the temperature increases, the steam required to produce the flame desired decreases, but this is counterbalanced by the extra steam used for heating the pitch–creosote.

With a view to improving steam consumption, atomizers with $\frac{1}{8}$-in. steam holes as against $\frac{3}{16}$-in. steam holes have been installed. Atomization is satisfactory and steam consumption has improved, but it is a little premature to quote figures.

Fuel Consumption

At the moment, the flow of pitch–creosote to each furnace is not metered ; weekly consumption is assessed from tank stocks. Consumption remains fairly constant by regulating according to delivery pressure observations, although as the percentage of pitch–creosote used increases, the degree of error becomes greater and the need for a suitable meter becomes much more marked. To eliminate irregularity and assist the furnace operator now that increased percentages of pitch–creosote have to be used, it has been decided to install meters to indicate the flow to each furnace, as shown in Fig. 7, although there seems to be a certain amount of difficulty in obtaining meters which will accurately indicate consumption of pitch–creosote at the low rate of flow.

During the campaign given in the notes on refractory consumption, when 50,464·3 tons of

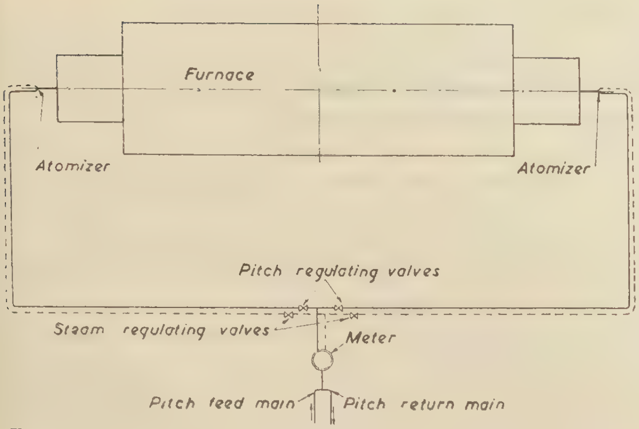

FIG. 7—Proposed arrangement of pitch–creosote and steam supply after installation of pitch–creosote meters

steel were produced, the fuel consumption for the whole campaign per ton of steel was 5,892,000 B.Th.U. This includes all fuel for warming-up and week-end gas. Excluding these items a figure of 5,605,000 B.Th.U./ton was obtained.

Qualities of steel produced during the above campaign :

0·10% of carbon and under	...	39%.
0·10–0·30% of carbon ...	...	56%.
0·30% of carbon and over	...	5%.

For a full campaign, the best figure so far attained is 4,893,500 B.Th.U. per ton of steel, excluding week-end and warming-up fuel, or 5,180,000 B.Th.U. if these items are included. All the above figures are calculated on the gross calorific values of coke-oven gas and pitch–creosote.

FURNACE OPERATION

Warming-up of the Furnace

The procedure adopted when bringing a coke-oven-gas-fired furnace into commission is to put small flares into the furnace for a period of 24–48 hr., 24 hr. usually being ample time. These flares are placed on old containers on the hearth of the furnace, and connected to the gas burner at either end of the furnace. When the temperature of the brickwork is at 700° C., the flares are removed from the furnace and gas is introduced and ignited at the burner. At the same time a quantity of steam, without pitch–creosote, is turned on at the atomizer to keep the flame off the roof and eliminate any danger of spalling. No trouble is experienced with spalling if these precautions are taken. Should the furnace be required to be brought into production quickly, it can be got ready for fettling in 24 hr. from gassing without any danger to the roof. To do this a quantity of gas (usually 10,000 cu. ft./hr.) is left on at the exit end of the furnace, which serves to heat-up the regenerators much more rapidly without causing too drastic a rise in the roof temperature, which would be the case if the same fuel input were put directly into the hearth of the furnace. Apart from leaving a proportion of gas on the exit end of the furnace, reversals are made at intervals of 10–15 min. This method of operation for warming-up the furnace is also used for the lifting of set charges, but in this case the amount of air used is reduced by approximately 30% to produce a long heavy flame and to provide additional heat in the regenerators.

Working of the Charge

The method of operation when working a charge on the coke-oven-gas-fired furnaces varies little from the procedure adopted on producer-gas-fired furnaces apart from the necessity to charge approximately 15% more oxides in the coke-oven-gas-fired furnace.

Having dried-up and repaired the furnace bottom after the previous charge has been tapped, the taphole is closed and fettling completed. A normal fettle is completed in 45 min. with an extra 15 min. to burn-in the dolomite and to bring the furnace up to a good temperature for charging. Pitch–creosote is turned off during fettling and the gas only is left on.

Charging is commenced and about 10 tons of scrap are put on the furnace bottom (occasionally 30–40 cwt. of lime are charged on the bottom), followed by the lime or limestone and oxides and the remaining portion of scrap. A further quantity of dolomite is thrown on the banks and breasts and the doors are banked-up before taking metal.

Scrap is charged as quickly as possible. The time taken from the commencement to the finish of charging of the cold materials varies from $2\frac{1}{2}$ to $3\frac{1}{2}$ hr. for 55 tons of scrap. It is usual for the metal to work-off the scrap immediately it is added, and a quantity of reaction slag is run off. During charging and melting about 60,000 cu. ft./hr. of coke-oven gas is consumed, with a sufficiency of pitch–creosote to ensure the desired length of flame, the air used being in the region of 425,000 to 475,000 cu. ft./hr. These quantities are reduced when the charge is melted, to 50,000 cu. ft. of gas and 400,000 cu. ft. of air per hour. The pitch–creosote consumption is also adjusted.

Melting is completed in 4–5 hr. after the hot-metal addition. When melted, a sample is sent to the laboratory for determination of nickel, copper, and tin. This is necessary due to the large proportion of low-carbon rimming steel at present made which calls for the presence of a minimum amount of these elements. Lime and spar are

added to the charge to ensure a good slag. Oxide and further quantities of lime are added.

Slag control in the true sense of the term is not practised. Were the total lime additions made before the addition of any oxides, time would be lost in the refining period due to the magnitude of the lime addition. It would be difficult to assess accurately the slag volume caused by the varying amounts of slag run off in the earlier stages of melting.

In most cases by the time the carbon is down to the required limits and the iron sufficiently high in the slag, the sulphur and phosphorus are within the limits specified. For the low-carbon rimming steel an iron content of 16–18% in the slag is aimed at.

Tap-holes are opened out with either tapping bars or an oxygen lance.

Additions of 10–15 lb. of aluminium are made in the ladle, the amount depending on the iron content of the slag and the condition of the charge. Minor adjustments are made with aluminium in the mould. Nozzles 1½ in. in diameter and 5-ton moulds are used for this class of steel.

With regard to the elimination of sulphur on the coke-oven-gas-fired furnaces, little difference is now noticed from the producer-gas units, although trouble was experienced in the early days, but this was probably due to the tendency to work the furnaces with insufficient air. If low sulphur steels are to be made this should be kept in mind.

Rimming steels produced in the coke-oven-gas-fired furnaces show no marked differences to rimming steels made in the producer-gas-fired furnaces. The same may be said of other classes of steel. Yields, and the amount of dressing on finished billets are similar for the two types of furnace.

Typical casts sheets are shown in Tables II–IV.

Removal of Slag from the Slag Pockets

The removal of slag from the slag pockets of the coke-oven-gas-fired furnace is much easier than from producer-gas-fired furnaces. A friable slag is produced which does not vary a lot in analysis from the producer-gas-fired furnace slag (the CaO and Fe are slightly higher). No doubt the difference in physical characteristics is influenced by the slightly lower temperature at which the slag pockets are worked as compared with the producer-gas-fired furnaces.

Below are some figures to indicate the comparative ease with which the slag is removed from the coke-oven-gas-fired furnaces' pockets :

Slag removal from producer-gas-fired furnace pockets ... ... 18·7 man-hours/ft.

Slag removal from coke-oven-gas-fired furnace pockets ... ... 13·7 man-hours/ft.

Factors Governing Smooth Operation

The chief factors which influence the smooth operation of coke-oven-gas-fired open-hearth furnaces to the greatest degree are :

(*a*) B.Th.U. value of the coke-oven gas.
(*b*) Position and slope of the gas burner.
(*c*) Design of the gas burner and the velocity of the gas.
(*d*) Unequal regenerator temperatures.
(*e*) Height of block-end slope adjoining air uptake.

The first essential to maintain output is, as on the producer-gas or any other type of gas-fired furnace, namely, a regular supply of gas of constant quality. If the calorific value of the gas falls below 490 B.Th.U./cu. ft., a considerable slowing up in the rate of production is noticed. This is no doubt due to the smaller heat input for a given quantity of gas, a slightly lower flame temperature, and the possibility of supplying too much air with the less rich gas. At the moment, little trouble is experienced with gas quality, the average thermal value being in the region of 530 B.Th.U. Before the installation of the modern coking plant, the gas supplied by the old type ovens was of a poorer quality, and constant attention to gas quality was necessary.

Approaching in importance to quality and supply of gas is the position and slope of the combined gas-and-pitch–creosote burner. A trial and error method has been used to achieve the ideal position for the burner. When the burner was too far forward, combustion occurred in close proximity to the exit end of the furnace and the short ramps of the roof were burnt. Withdrawal of the burner an excessive amount caused the roof immediately over the back lining, particularly over the tap-hole, to wear rapidly, also occasionally the knuckle nearest the burner was damaged. Eventually the best position was found to be where the burner nose was 6 ft. 9 in. from the centre line of the knuckle. The burner is set in such a position that a distance of 3 ft. 1½ in. separates the sill level and the burner nose. It is important that the distance between burner level and slag level is not too great otherwise foaming will occur due to the gas riding too high, also, heat transfer to the metal will not be efficient.

The angle at which the burner is placed is influenced by the high pressure and velocity of the gas. An angle of 14° has been found to give the best results. If the burner is set at a steeper angle, the flame spreads badly on to the linings ; at the same time it is reflected from the charge to the roof in a fashion rather similar to a ray of light striking a mirror, the angle of reflection being controlled by the angle of incidence (Fig. 8).

With regard to the design of gas burners, much

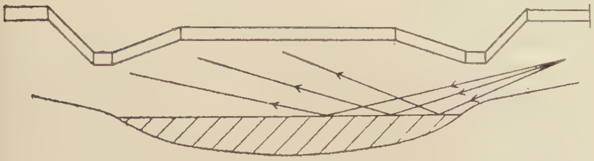

FIG. 8—Effect of slope of burner on flame direction

work has been done on various types, and perhaps a summary of the changes that have taken place during the last few years will give an indication of the trend in design. Originally the gas-and-tar burner (tar was used as an illuminant for a considerable period) entered the furnace at the charging side of the port end, and was constructed with a right-angle bend to direct the gas and tar in the longitudinal direction of the furnace. Inaccessibility to clean the tar pipe out and inability to clear away slag, &c., from the front of the burner were the reasons for discontinuing the use of this type of burner.

It was then decided to redesign the furnace ends and install straight burners. The gas-and-tar burners were two separate water-cooled tubes, through which the gas and tar were conveyed to the furnace, the tar tube being clamped horizontally on top of the gas tube. Trouble was experienced in keeping the two tubes in alignment and for this reason the tubes were combined in one water-cooled cylinder.

TABLE II—*Example No. 1, Rimming Steel, Carbon 0·06% max.*

Pit sample analysis :

	C, %.	Si, %.	S, %.	P, %.	Mn, %.	Ni, %.	Cu, %.	Sn, %.
Specification ...	0·06	...	0·035	0·020	0·30–0·35	...	...	...
Cast analysis (a) ...	0·06	trace	0·033	0·020	0·33	0·14	0·12	0·01
Cast analysis (b) ...	0·06	trace	0·034	0·020	0·33	...	...	...

Charge :

	Tons.	Cwt.	Tons.	Cwt.
Scrap :				
Turnings	18	10	...	...
Mill scrap	14	0	...	...
Mixed heavy scrap	12	10	...	...
Total			45	0
Oxide			8	0
Limestone			11	5
Hot metal			57	12

Hot metal analysis :

Si, %.	S, %.	P, %.	Mn, %.
0·47	0·045	1·35	1·10

Working of charge :

6.20 A.M. ...	... Time of last tap.
8.0 A.M. ...	... Commenced charging.
10.40 A.M. ...	... Finished charging all cold materials.
12.30 P.M. ...	... Hot metal added.
3.15 P.M. ...	... 20 cwt. of lime, 12 cwt. of spar.
3.40 P.M. ...	... 20 cwt. of lime.
4.15 P.M. ...	... 20 cwt. of lime.
4.35 P.M. ...	... 20 cwt. of lime, 25 cwt. of scale ; analysis sample taken (C, 0·46% ; S, 0·06% ; P, 0·30% ; Mn, 0·38% ; Fe in slag, 6·5%).
5.20 P.M. ...	... 20 cwt. of lime, 25 cwt. of ore.
5.45 P.M. ...	... 20 cwt. of lime.
6.15 P.M. ...	... 20 cwt. of lime.
6.30 P.M. ...	... Analysis sample taken (C, 0·13% ; S, 0·05% ; P, 0·05% ; Mn, 0·16% : Fe in slag, 11·0%).
6.50 P.M. ...	... 20 cwt. of lime.
7.15 P.M. ...	... Analysis sample taken (C, 0·08% ; S, 0·04% ; P, 0·03% ; Mn, 0·14% : Fe in slag, 15·5%).
7.35 P.M. ...	... Furnace tapped.

Tapping slag analysis :

CaO, %.	Fe, %.	P_2O_5, %.	SiO_2, %.
50·8	16·5	9·05	8·1

Ladle additions :

Ferromanganese ...	10 cwt. 3 qr.
Aluminium	12 lb.

Weight of ingots produced : 96 tons 12 cwt.

At about the same time that this change was made, experiments were being carried out on the effect of the burner nozzle size in relation to flame direction and B.Th.U. consumption per ton of steel produced, &c. Shortages of coke-oven gas were being experienced following difficulties at the coke-oven plant, as a result of which the input of gas to each open-hearth furnace had to be reduced from an hourly average consumption of 70,000–75,000 cu. ft. to 55,000 cu. ft., the difference in heat input to be derived from extra tar. When this reduction in gas consumption was made the fuel consumption in B.Th.U. per ton of steel increased and output deteriorated, although the actual heat input per hour remained unaltered. The speed of the flame was now particularly slow, accompanied with poorer direction and increased liability to damage the roof. The gas burners at this time were $5\frac{1}{2}$ in. in diameter. To increase the velocity of the gas it was decided to fit machined inserts in the burner aperture to reduce the area of the opening. The effect of the installation of these machined inserts was immediate. Furnace working was improved, roof and linings remaining much cooler, and the charge was much easier to manipulate with a considerable reduction in the B.Th.U. required per ton of steel. Following this change, further reductions in the size of the burner nozzle were made until, finally, the aperture diameter was reduced to $3\frac{1}{2}$ in. If reduced beyond $3\frac{1}{2}$ in. it is impossible to get sufficient fuel into the furnace at the pressure at which it is now delivered by the booster (20–22 in. W.G.). Details of gas delivery at the furnace are as follows :

Gas pressure before gas valve ...	19–20 in. W.G.
Gas velocity at burner nozzle ...	210–250 ft./sec.
Gas pressure at burner nozzle (open end)	11 in. W.G.

The eventual result of this gradual reduction in burner size was to produce an output in the region previously achieved before the reduction in gas consumption was made, also, the total fuel consumption was reduced by 15–20%. When conditions returned to normal at the coke-ovens it was possible by this saving, together with other small cuts in fuel in various parts of the works, to convert another furnace from producer-gas to coke-oven-gas firing. A further change was tried : by altering the round nozzle of the gas burner to a rectangular shape it was hoped to

Table III—*Example No. 2, Free-Cutting Steel*

Pit sample analysis :		C, %.	S, %.	P, %.	Mn, %.
Specification		0·13(max.)	0·22–0·24	0·06	0·80–0·85
Cast analysis (a)		0·11	0·235	0·051	0·83
Cast analysis (b)		0·12	0·240	0·053	0·81

	Tons.	Cwt.	Tons.	Cwt.
Charge :				
Scrap :				
Turnings	25	4	...	...
Skull	11	1	...	...
Mill scrap	15	4	...	...
		Total	51	9
Oxides :				
Thabazimbi ore		...	5	0
Scale		...	2	10
Limestone		...	11	5
Hot metal		...	56	0

	Si, %.	S, %.	P, %.	Mn, %.
Hot metal analysis :	0·42	0·05	1·40	1·01

Working of charge :

6.5 P.M.	Time of last tap.
7.5 P.M.	Commenced charging.
9.55 P.M.	Finished charging cold materials.
12.00 Midnight	Hot metal added.
3.45 A.M.	20 cwt. of lime.
4.5 A.M.	20 cwt. of lime.
4.30 A.M.	20 cwt. of lime ; analysis sample taken (C, 0·25% ; S, 0·10% ; P, 0·20% ; Mn, 0·21% : Fe in slag, 7·0%).
5.0 A.M.	20 cwt. of lime ; analysis sample taken (C, 0·12% ; S, 0·09% ; P, 0·05% ; Mn, 0·19% : Fe in slag, 10·5%).
5.55 A.M.	Furnace tapped.

	CaO, %.	Fe, %.	P_2O_5, %.	SiO_2, %.
Tapping slag analysis :	47·0	14·0	11·50	9·5

Ladle additions :

Ferromanganese	27 cwt.
Rock sulphur	$5\frac{1}{2}$ cwt.

Weight of ingots produced : 101 tons 5 cwt.

spread the flame more evenly over the bath, but this proved a failure. At the moment certain other alterations are being tried to burners and atomizers with a view to increased efficiency. It will have been noticed that a rather contradictory procedure is adopted when the pitch–creosote is introduced to the furnace, *i.e.*, the pitch–creosote is heated, atomized, and then suffers the effect of passing through a water-cooled tube before entering the furnace. Whilst this method of injection has proved quite effective and has given very little trouble, some improvement might be made by the elimination of the cooling effect of the water surrounding the pitch–creosote tube. With this in mind the pitch–creosote tube has been inserted inside another tube, and the space between the inner and outer tube has been packed with insulating material.

Trials with a number of types of atomizers have been made in the atmosphere, using compressed air and water as the test media instead of pitch–creosote and steam, to give a visible indication of the effectiveness of each type of atomizer. It was noticed that the vapour produced both from intricate and simple atomizers varied little. It was of particular interest to see the effect of increasing quantities of air on a constant flow of water. In the first case a small amount of air was allowed to pass through the atomizer; this broke the jet of water into large globules. As increasing quantities of air were used the size of the water drops became proportionately smaller, until a very fine vapour was produced. Further quantities of air did not appear to affect the vapour beyond this point, apart from increasing the velocity and strengthening the direction of flow of the vapour. These trials confirmed our experiences regarding the effect of the use of steam on the pitch–creosote flame during different stages of the process in the furnace.

TABLE IV—*Example No. 3, Forging Quality, Carbon* 0·29–0·32%

Pit sample analysis :	C, %.	Si, %.	S, %.	P, %.	Mn, %.
Specification	0·29–0·32	0·15–0·25	0·05	0·05	0·75–0·80
Cast analysis (a)	0·30	0·226	0·040	0·045	0·82
Cast analysis (b)	0·30	...	0·040	0·045	0·83

Charge :	Tons.	Tons.	Cwt.
Scrap :			
Turnings	25·1	...	...
Pit scrap	11·3	...	...
Mixed heavy	8·16	...	...
	Total	45	
Oxides :			
Thabazimbi ore		5	0
Scale		2	10
Lime		6	0
Hot metal		60	0

Hot metal analysis :	Si, %.	S, %.	P, %.	Mn, %.
	0·42	0·045	1·32	1·05

Working of charge :

12.0 Noon	Time of last tap.
1.15 P.M.	Commenced charging.
3.50 P.M.	Finished charging all cold materials.
6.15 P.M.	Hot metal added.
9.50 P.M.	20 cwt. of lime, 6 cwt. of spar.
10.10 P.M.	20 cwt. of lime.
10.30 P.M.	20 cwt. of lime.
10.45 P.M.	20 cwt. of lime, 25 cwt. of ore.
11.15 P.M.	20 cwt. of lime; analysis sample taken (C, 0·60%; S, 0·06%; P, 0·08%; Mn, 0·23%: Fe in slag, 8·0%).
11.35 P.M.	20 cwt. of lime, 25 cwt. of scale.
11.50 P.M.	20 cwt. of lime.
12.0 Midnight	Analysis sample taken (C, 0·34%; S, 0·05%; P, 0·04%; Mn, 0·20%; Fe in slag, 10·5%).
12.30 A.M.	Furnace tapped.

Tapping slag analysis :	CaO, %.	Fe, %.	P_2O_5, %.	SiO_2, %.
	55·0	11·0	10·21	9·5

Ladle additions :	
Ferromanganese	22 cwt. 1 qr.
45% Ferrosilicon	12 cwt.
Anthracite coal	100 lb.
Aluminium	40 lb.
Weight of ingots produced :	98 tons.

The direction and sharpness of the flame can be influenced appreciably by the amount of steam being used. During charging, a greater quantity of steam is passed, the effect of which is to produce a rather short but keen flame ideal for the melting down of the scrap. For refining, the quantity of steam is reduced to give a longer and heavier flame, which assists the boil and eliminates the tendency to foam.

Another difficulty experienced with coke-oven-gas-fired open-hearth furnaces was to maintain both of the regenerators at each end of the furnace at the same temperature. For a period after bringing a furnace into commission little trouble was experienced and the regenerators maintained fairly even temperatures, but gradually after a few weeks' operation the outer regenerator chambers would lose temperature, and became made-up with deposit which conforms to the following analysis :

CaO, %.	S, %.	Fe, %.	Mn, %.	Carbonaceous matter.
19·0	9·14	34·4	0·64	Nil.

Simultaneously, the outer air uptakes would make up with slag and drippings from the brickwork, until finally the outer regenerators ceased to function to any great extent. The loss of the use of the outer regenerators reduced the effective regenerator capacity by approximately 40%, and threw all the load on to the inner regenerators. Various remedies were tried to overcome this problem. The use of auxiliary dampers to facilitate the variation of the draught through individual regenerator chambers was considered, but the layout of the valve pit prevented the installation of these dampers. Staggering of the inner-chamber regenerator bricks, leaving the outer-chamber regenerators with straight-through openings was tried, hoping that this would create a little more draught in the outer chambers, but no improvement was noticed. The next alteration tried was to restrict the size of the inner uptakes, but results were again negative. Finally the difficulty was overcome to a great degree by lifting the outer uptake arch *A* and lowering the partition wall *B* (Fig. 1 (*b*)) between inner and outer uptakes. This alteration increased the area of the opening to the outer chambers by approximately 33%. At the same time the regenerator bricks in the outer chambers were left slightly lower. Since this alteration has been made to the furnace, a certain amount of make-up occurs in all uptakes, but to a much less degree than formerly, and it is such that it gives little trouble. When the furnace is taken off for repairs the deposit in the uptakes is cut down with ease, leaving the original brickwork intact, and it is necessary to renew only the upper portion of the shafts. Since the regenerator temperatures have been equalized, the furnaces have worked much better and with easier control of roof temperature. This is no doubt due to the smaller range through which the temperatures of the regenerators fluctuate, which in turn would produce a more even flame temperature with the high peak temperatures eliminated. Regenerator life has been enhanced by the alteration, with improvements in the amount of bricks recoverable from regenerators when repairs are carried out. Regenerator temperatures vary from 1050° to 1200° C.

Bearer arches for the support of the regenerator bricks have been lifted from a height of 3 ft. to 4 ft. from the paving of the chamber to the underside of the bearer. This allows the men employed on furnace repairs, to remove rubbish, &c., without the necessity to remove the bearer blocks.

Whilst dealing with the subject of regenerators it may be of interest to mention the possibility and desirability or otherwise of the use of a single chamber for the regenerators at each end of the furnace rather than having two chambers of smaller dimensions. The mixer on the shop under discussion is operated with a single chamber at each end of the furnace and no trouble is experienced, although the temperature conditions are slightly less than those experienced in steel furnaces. Each chamber has a capacity of 6,466 cu. ft. Regenerator chambers up to 21 ft. in width are mentioned in a paper by Knight [3] as giving no trouble. In the interests of flexibility some operators would prefer to retain the two regenerator chambers at each end of the furnace and in the event of a change in the method of firing becoming necessary, say due to works policy, the change to producer gas could be accomplished with much less trouble.

Improvement in draughting in the coke-oven-gas-fired furnace can be made should it be necessary to prolong the life of a furnace to fit in with the repair programme of the shop. This is accomplished either at the week-end or during the week, and if it is done during the week, preferably when the scrap is being charged. The procedure adopted is to leave the gas on one end of the furnace for a period, remove the regenerator wicket stopping and take out sufficient checkers to improve the draught. Little delay is caused to the furnace when the repairs are carried out in instalments. If the draughting is poor in the furnace, the gas burner is inclined to soot-up quickly and requires cleaning two or three times a day ; at the same time the furnace roof gets too hot.

A considerable amount of influence is exerted on the length of the flame in the coke-oven-gas-fired furnace by the variation, either upwards or downwards, of the apex *C* formed by the block-end-slope brickwork and the air-uptake shaft (Fig. 1 (b)). If this point is too high, combustion is accelerated and a short flame is produced which tends to damage the short ramps at the ingoing end of the furnace. When point *C* is lowered an excessive amount, extension of the flame takes place which results in the short ramps at the exit end of the furnace becoming subject to rapid wear. The ideal position for apex *C* has been found to be 2 ft. 2½ in. above sill level.

Refractories

Under identical operational conditions (same hot-metal/scrap ratio and same steel programme) a more favourable refractory cost is obtained on the coke-oven-gas-fired furnaces, when compared with the producer-gas units.

An approximate life of various parts of both producer-gas-fired and coke-oven-gas-fired furnaces is given below :

	Producer-gas-fired furnace. Weeks.	Coke-oven-gas-fired furnace. Weeks.	
Front lining ...	8–10	10–13	
Back lining ...	18–22	12–14	(straight back wall).
Main roof ...	18–22	19–23	
Port-end roof ...	18–22	19–23	(occasionally runs full campaign).
Regenerator bricks recovered ...	0–10%	25–50%	

The average refractory consumption per ton of steel for both coke-oven-gas-fired and producer-gas-fired furnaces for the last five years is :

	Refractory consumption, lb.
Firebrick	11·22
Silica brick	21·71
Magnesite	1·51
Chrome—magnesite	4·76

In actual cost for this period, wages and refractory materials have been 10% less on the coke-oven-gas-fired units than on the producer-gas-fired furnaces.

On completion of general repairs, a campaign of 40–50 weeks is expected on the coke-oven-gas-fired furnaces. A mid-campaign repair is usually made when the roof and linings are repaired, and the slag is removed from the pockets.

Repairs carried out before the commencement of the campaign :

(i) Roof was entirely renewed (12 in. thick).
(ii) Back and front linings were entirely renewed.
(iii) Blocks were renewed; water-cooled jackets were not changed.
(iv) Fairly extensive repairs were made to upper portion of the uptakes.
(v) All regenerators were rebuilt. 30% of the regenerator bricks from the previous campaign were recovered and were incorporated.
(vi) All of the slag was removed from pockets, and slag-pocket walls were patched.
(vii) All flues were cleaned out.

A typical log of a campaign of a furnace having a straight back wall, together with repairs carried out at the week-ends, and the tonnages produced, is given below :

Week.	Tonnage Produced.	Week-end Repairs.
1.	994·6	—
2.	1085·2	Jambs pasted.
3.	716·14	Jambs pasted.
4.	1036·16	Jambs pasted.
5.	1165·8	Jambs pasted.
6.	1075·13	Jambs pasted.
7.	1206·7	Jambs pasted.
8.	1219·2	Jambs pasted.
9.	1274·9	Jambs pasted.
10.	1251·13	Large patch in back lining.
11.	1226·18	Front lining renewed.
12.	1093·13	Jambs pasted.
13.	1109·2	Jambs pasted.
14.	1244·14	Jambs pasted.
15.	1086·0	Jambs pasted.
16.	1320·16	Small roof patch over tap-hole.
17.	1361·17	Back lining patched.
18.	1214·6	Back lining patched.
19.	1239·12	Front lining patched.
20.	1091·0	Patch on back lining.
21.	1089·14	Small patch in roof.
22.	929·18	Small patch in east-end-port roof.
23.	1106·6	None.
24.	327·14	None.
	26,467·0	

The furnace was then taken off for a mid-campaign repair, the following renewals being made :

(i) New 12-in. roof.
(ii) Front and back linings.
(iii) Block ends were repaired.
(iv) Top 3 or 4 ft. of uptakes were repaired.
(v) Slag was taken out of the pockets.
(vi) Regenerators were not touched but flues were cleaned out.

The above repairs having been completed, the furnace was put into commission for a further twenty-one weeks, producing the following :

Week.	Tonnage Produced.	Week-end Repairs.
1.	868·0	None.
2.	1129·3	Jambs pasted.
3.	1082·1	Jambs pasted.
4.	888·8	Jambs pasted.
5.	1342·12	No. 1 door arch renewed.
6.	1109·2	Jambs pasted.
7.	1054·15	Jambs pasted.
8.	1107·3	Jambs pasted.
9.	1106·3	Front lining repaired.
10.	1169·7	Jambs pasted.
11.	1132·3	Jambs pasted.
12.	1313·3	Patch in back lining.
13.	1233·1	Front lining patched.

Continued on next page

Week.	Tonnage Produced.	Week-end Repairs.
14.	1038·1	Patch in back lining.
15.	1219·8	Patch in back lining.
16.	1362·14	Jambs pasted.
17.	1338·17	Front lining patched.
18.	1221·18	Jambs patched.
19.	1252·14	Jambs patched.
20.	1020·14	Jambs patched.
21.	1007·16	—
	23,997·3	

Total steel production during the campaign ... ... 50,464·3 tons.

Analysis of steel produced :
- 0·10% of carbon and under ... 39%.
- 0·10–0·30% of carbon ... 56%.
- 0·30% of carbon and over ... 5%.

The last roof to be taken off this particular furnace had produced 37,000 tons, and the average for the previous 12 roofs was 24,599 tons. This average includes one roof which made 7143 tons, which was put on to lift a set charge and was knocked-in a few weeks later when the furnace was taken off for general repairs and the condition of the skewback channels did not warrant leaving the roof on. Excluding this roof, the average tonnage produced for each 12-in. roof is 26,186 tons. An average figure taken on the producer-gas-fired furnaces for a similar period was 21,118 tons.

Outputs

The normal output on a programme consisting of 40% of rimming steel of composition 0·065% of carbon max., and 0·035% of sulphur, and the remainder mixed qualities of up to 0·4% of carbon is 1100 tons per week. The record weekly output is 1470 tons. For a full campaign (excluding one broken week) the best weekly average is 1275 tons. Operating with a chrome–magnesite roof and linings, the record weekly output from the coke-oven-gas-fired furnaces is 1615 tons.

Conclusions

Relative to the method of firing of open-hearth furnaces, enumerated below are a number of the more important points which are favourable to the cold-coke-oven-gas-fired furnace.

(1) To meet fluctuating supplies of gaseous and liquid fuel it is possible on the type of furnace under discussion to use from 0 to 100% of either liquid fuel (oil, pitch–creosote, or tar) or coke-oven gas, with only slight modifications being made to the atomizer. These modifications can be accomplished in a matter of minutes. With the deterioration in the gas-coal supply and the increase in its cost, which tends to make the importation of cheap fuel oil a possibility, the importance of the above flexibility is multiplied.

(2) With the possibility of the week-end stoppage being eliminated in the future, a continuous 7-day week will be worked. Furnaces fired with coke-oven gas could be operated from the commencement to the completion of the campaign without flue cleaning, &c., the only stoppages being for lining and other minor repairs.

(3) It is highly probable that the "all basic" chrome–magnesite furnace will be the furnace of the near future. As is well known to users of chrome–magnesite, it is essential to maintain the brickwork as free from temperature fluctuations as possible to minimize the peeling common to this type of refractory. The temperature fluctuations can be minimized to a great extent by leaving a proportion of the coke-oven gas on the furnace over the week-end.

(4) Little trouble is experienced with foaming charges on the coke-oven-gas-fired furnace as compared with the mixed-gas-fired furnace.

(5) Accessibility to furnace regenerators whilst the furnace is working, and the simplicity of the stack flue and air-valve layout.

(6) At the moment the coke-oven-gas-fired open-hearth furnace is confined to integrated steelworks. With the probable extension of the gas grid in various districts, the possibility of further steelworks using coke-oven-gas units is increased.

(7) In the case of mixers, active or otherwise, certain advantages are to be gained if coke-oven gas and pitch–creosote are used for fuel. This is particularly so if one mixer only is employed in the open-hearth department. It is possible to continue to operate the coke-oven-gas-fired mixer as an inactive container, whilst the furnace is being rechekered and the slag pockets cleaned out. This is accomplished by keeping the gas on one end of the furnace for the period the repairs are being carried out, recheckering proceeding at the end of the furnace at which the gas is burning.

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A Note of the Mode of Occurrence of Tellurium in Cast Iron*

By H. Morrogh†

Synopsis

The unique features of the influence of tellurium in cast iron have been emphasized. By metallographic means employing the polarizing microscope it has been shown that in the presence of an excess of manganese over that required to neutralize the sulphur, tellurium forms manganese ditelluride. With no manganese or with insufficient manganese to balance the sulphur, iron monotelluride is formed. Various aggregates of manganese sulphide, manganese ditelluride, iron sulphide, and iron telluride are described.

Introduction

The addition of tellurium to cast iron is an established commercial process, and the effects of this element upon the material have been described from time to time in the literature.[1, 2, 3] During the solidification of cast iron, tellurium behaves as a powerful carbide stabilizer and this factor has led to its application in the production of white and chilled iron castings.[4, 5] It has also found application in the malleable-iron industry,[6] in which case it is claimed that additions of tellurium permit the use of higher silicon contents than can normally be employed to give white-iron castings. Such castings will subsequently graphitize rapidly on annealing, due to their relatively high silicon contents. Whether the carbide stabilizing influence of tellurium is less at temperatures used for the annealing of malleable iron than at the solidification temperature is not known; but quite definitely the element exerts a carbide stabilizing influence in both cases.

As a carbide stabilizer tellurium does not behave normally. It will cause the outer rim of a sand-casting to solidify white, with a grey core; this effect is unusually sensitive to pouring temperature,[7] and the line of demarcation between the white rim and the grey core is usually very sharp. In these respects tellurium differs from sulphur, but the difference becomes more interesting when it is remembered that the carbide stabilizing influence is obtained regardless of the manganese content. Sulphur in the form of manganese sulphide does not appear to influence carbide stability, but when present as iron sulphide (FeS) its carbide stabilizing influence is pronounced.

When the unique features of tellurium as an alloying element in cast iron are considered along with the chemical similarity of the elements sulphur and tellurium, it is obvious that some considerable interest is shown as to the mode of occurrence of the latter element in cast iron. In the following an account is given of various observations which throw some light on this subject.

Metallographic Observations

In a paper dealing with the influence of tellurium upon steel, Waterhouse and Zavarine[8] have noted the occurrence of a phase, lighter in colour than manganese sulphide, in a steel containing 0·64% of manganese, 0·039% of sulphur, and 0·12% of tellurium. This phase was provisionally termed "iron telluride" by these authors. A similar phase has been observed by the present author in all cast irons containing more than sufficient manganese to balance the sulphur content,‡ to which tellurium has been added.

The phase is a very light dove-grey colour, under the metallurgical polarizing microscope it exhibits no anisotropy, it is allotriomorphic in outline, and it frequently occurs associated with manganese sulphide and occasionally with graphite. Figure 1 shows a typical aggregate of manganese sulphide and the new phase surrounded by a ring of graphite. Frequently the new phase and the manganese sulphide occur associated in a

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‡ Here, as in other parts of this paper, this is meant to imply sufficient manganese according to the well-known formula Mn, % = $0\cdot3 + (1\cdot7 \times S,\%)$.

eutectic-like structure with manganese sulphide as the dispersed phase; Fig. 2 is a typical example of this. When the tellurium addition is made to an iron which also contains titanium, the titanium carbide which is usually randomly distributed becomes segregated around the periphery of the manganese sulphide–tellurium-phase aggregates. This is illustrated in Fig. 3.

The examples quoted so far are typical of a wide variety of irons containing tellurium which have been examined and which cover the range 2·5–3·6% of total carbon, 0·4–3·0% of silicon, 0·4–1·0% of manganese, 0·04–1·4% of phosphorus, and up to 0·18% of sulphur.

According to the literature [9, 10, 11] the existence of two manganese tellurides has definitely been established. Manganese telluride (MnTe) is reported as having a nickel arsenide type of structure and manganese ditelluride ($MnTe_2$) is reported as having a pyrites type of structure. The monotelluride would therefore be expected to be optically anisotropic whilst the ditelluride would be optically isotropic. Therefore, since the tellurium phase which has been described so far is optically isotropic, and if the tellurium is combined with manganese, then the phase is very probably manganese ditelluride.

To test this a synthetic melt was made with a very low manganese content, tellurium was added, and a small ingot of 0·875-in. dia. was poured in green sand. The melt was then treated with manganese and a second ingot was poured. The melt was carried out in a small high-frequency induction furnace and the charge consisted of wrought iron, electrode carbon, and elemental silicon. The ingot poured after treatment with 0·3% of tellurium had the following analysis:

Total C, %	Si, %	Mn, %	S, %	Te, %
3·23	1·06	0·07	0·004	0·137

The microstructure of this sample was that of a typical hypo-eutectic white iron as would be expected from the analysis. The minor phases in this sample were all of one type but were unlike those which have been described above as occurring in irons containing manganese. The phase present was found to be pleochroic, and so its colour under the metallurgical microscope depended upon the orientation of the particle with reference to the plane of polarization of the light reflected from the vertical illuminator which is always partially plane-polarized.[12] Each particle was found to consist of two or more crystals, the colour of which ranged from dark grey, in the position of maximum absorption, to light tan in the position of minimum absorption. This effect could, as would be expected, be intensified by placing a polarizer in the illuminating train. Under polarized light between crossed nicols the phase exhibited a marked optical anisotropy, lighting up four times for a complete revolution of the microscope stage. Owing to the allotriomorphic character of the phase it was not possible to relate these optical properties to any features of external symmetry. Figure 4 (*a*), which illustrates these optical properties, shows a typical aggregate under plane-polarized light. Figure 4 (*b*) shows the same aggregate under plane-polarized light but after a 90° rotation of the specimen. The crystals of the aggregate which are dark in Fig. 4 (*a*) are light in Fig. 4 (*b*) and *vice versa*. Figure 4 (*c*) shows the same spot between crossed nicols with one crystal in its position of maximum brightness.

Chemical analysis of the second ingot, cast after an addition of manganese metal, gave 0·78% of manganese and 0·103% of tellurium. The minor phases in this sample were all of the same type and were the same as those which have been described above as associated with manganese sulphide. They were allotriomorphic, optically isotropic, and a light dove-grey in colour. As this phase is only formed in cast iron containing both manganese and tellurium, it would seem that the assumption made above that it is manganese ditelluride is sound.

It follows from this experiment that the form of the tellurium in a cast iron depends upon the presence or absence of manganese. In the presence of manganese the optically isotropic manganese ditelluride is formed, and in the absence of this element an optically anisotropic iron telluride is formed. According to the literature,[10, 11, 13] iron telluride (FeTe) has a hexagonal crystal structure and is fairly stable, whereas iron ditelluride ($FeTe_2$) has a marcasite type of structure and is unstable. It would seem therefore that the pleochroic anisotropic phase formed in the absence of manganese is iron telluride (FeTe).

To investigate the relationships existing between tellurium and sulphur in the presence of insufficient manganese to combine with both the sulphur and tellurium, various synthetic melts were made-up to give varying amounts of all three elements. It was found that iron sulphide and iron telluride can co-exist in aggregates giving eutectic-like structures. Figure 5 shows a typical aggregate in a sample of the following analysis:

Mn, %	S, %	Te, %
0·07	0·22	0·23

Figure 5 shows an aggregate of iron sulphide and iron telluride with the latter phase in its position of minimum pleochroic absorption; the dark

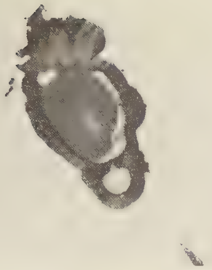
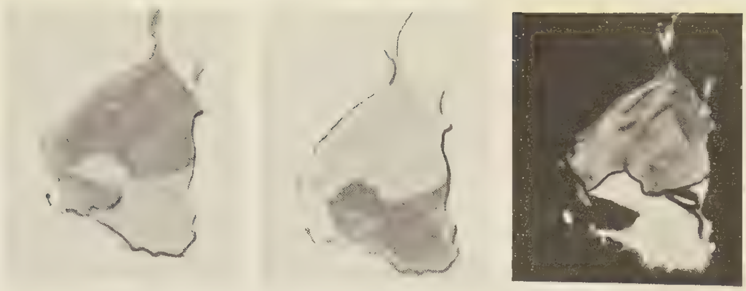


FIG. 1—Manganese sulphide (dark) associated with manganese ditelluride (light) surrounded by a ring of graphite. Unetched × 2500



(a) (b) (c)

FIG. 4—An area of iron telluride under (*a*) plane-polarized light; (*b*) plane-polarized light but after a stage rotation of 90° and (*c*) plane-polarized light between crossed nicols. Unetched × 1200

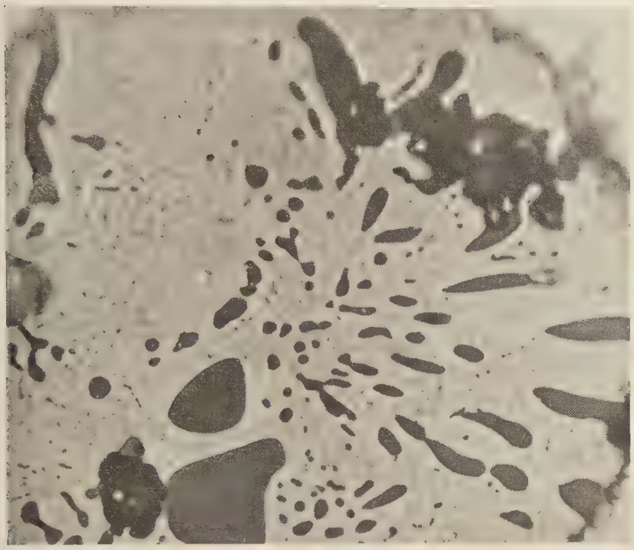
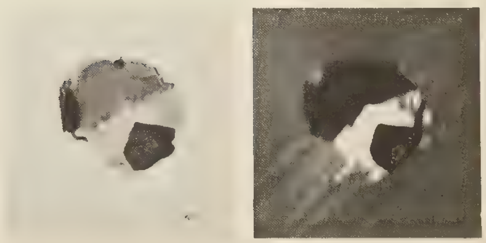


FIG. 2—Eutectic-like aggregate of manganese sulphide (dark) and manganese ditelluride (light continuous phase). Unetched × 2000



(a) (b)

FIG. 5—An aggregate of manganese sulphide, iron telluride, and manganese ditelluride; (*a*) under plane-polarized light and (*b*) between crossed nicols. Unetched × 1500

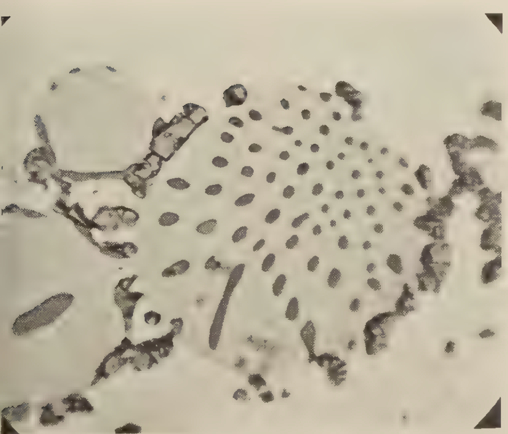
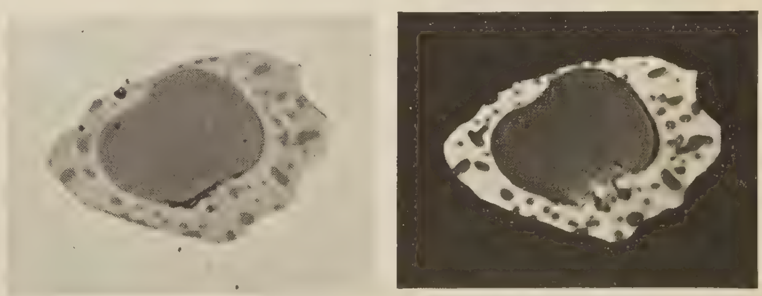


FIG. 3—Segregation of titanium carbide crystals around a manganese ditelluride/manganese sulphide aggregate. Unetched × 1200



(a) (b)

FIG. 6—An iron sulphide/iron telluride aggregate; (*a*) under plane-polarized light with iron telluride (light) in position of minimum absorption and (*b*) between crossed nicols. Unetched × 1500

The photomicrographs reproduced here were taken with a 2 mm. oil immersion achromat N. A. 1·3

The Manufacture of Steel in the Acid Open-Hearth Furnace by the Scrap-Carbon Process*

By B. Yaneske†

Synopsis

Because of the scarcity in India of imported hematite pig iron for operating the pig-and-scrap process in the acid open-hearth furnaces, the author successfully introduced the scrap–carbon process using 100% of steel scrap, in order to maintain essential supplies of high-grade acid steel.

In operating the scrap–carbon process, the deficit of carbon in the charge is made good by the use of petroleum coke, and the deficit in silicon by the addition of acid slag to the molten bath. The furnace hearth is protected from erosion during the melting of the scrap by spreading an easily fusible silica sand over the banks before charging, whilst manganese is introduced into the bath by the employment of manganese ore instead of iron ore for oxidizing the carbon.

The history of a nickel–chromium steel heat made by the scrap–carbon process is given as an example, and it is possible to make regularly any composition of steel by the standard practice adopted in India.

The quality of the steel manufactured by the scrap–carbon process described is quite as high as that obtained by the pig-and-scrap process. The acid hearths are not destroyed any more by the former than by the latter process, and the average time of heats from tap to tap has not been increased by the adoption of the scrap–carbon process. The yield of ingots from the metal charged is higher by the scrap–carbon process, whilst no difficulty has been experienced in obtaining the desired tapping temperature of the steel made by this process.

Owing to the acute shortage of imported hematite pig iron in India for operating the normal pig-and-scrap process in acid open-hearth furnaces, it was found necessary to introduce the scrap–carbon process as a war-time measure and thus work the heats with 100% of steel scrap, *i.e.*, entirely without pig iron, so as to maintain the essential supplies of the highest grade of acid steel.

Since its introduction in India by the author in June, 1940, many hundreds of heats have been worked successfully by the scrap–carbon process without damaging the acid hearths or furnace structures any more than by the pig-and-scrap process, whilst the quality of steel produced has been quite as high as that obtained by the latter process.

In the scrap–carbon process as operated in India, the deficit of carbon in the charge is made good by the use of petroleum coke, and the deficit in silicon by the addition to the molten bath of acid finishing slag from previous heats. The banks of the furnace are protected from erosion during the melting of the scrap by the use of an easily fusible silica sand of moderately low silica content, such as foundry moulding sand or rivér sand, which is spread around the banks just before commencing to charge the furnace.

* Received 30th July, 1942. Circulated confidentially during the war, in Advance Copy form.

† The Tata Iron and Steel Co., Ltd., Jamshedpur, India.

TABLE I—*History of a Typical Charge*

Cast No. 4493: April 23rd, 1941.
Grade of steel: Nickel–chromium.

Chemical Composition

C, %.	Mn, %.	S, %.	P, %.	Si, %.	Ni, %.	Cr, %.
0·55–0·63	0·40–0·50	0·04 max.	0·04 max.	0·20–0·30	2·70–2·90	1·90–2·40

Charge (20-ton acid open-hearth furnace, hand-charged)

	Tons.	Cwt.	Qr.	Lb.
Petroleum coke	0	9	0	0
Rail steel scrap	1	3	0	0
Nickel steel scrap	11	11	1	22
Nickel–chromium steel scrap	7	5	2	6
Total scrap charged	20	0	0	0

	Time.
Commenced hand-charging	2.10 A.M.
Finished hand-charging	6.10 ,,
Charge melted	9.15 ,,
Furnace tapped	1.00 P.M.

Additions of Sand and Slag

		Time.
Moulding sand	(5 cwt.)	2.05 A.M.
Acid slag	(10 cwt.)	8.15 ,,
Acid slag	(5 cwt.)	fed into bath at intervals

Bath Samples.

Time.	C, %.	Ni, %.	Cr, %.
10.10 A.M.	0·97	2·35	0·39
10.35 ,,	0·84		
11.05 ,,	0·76		
11.30 ,,	0·71		
11.55 ,,	0·63		
12.10 P.M.	0·55		
12.30 ,,	0·50		

Additions to Bath during Working of Heat.

	Cwt.
Manganese ore (Mn 42·9%; SiO_2 2·92%) ...	$2\frac{1}{2}$
Limestone	$1\frac{1}{2}$

Additions of Alloys to Bath

	Cwt.	Qr.	Lb.	Time.
Nickel	2	2	0	11.45 A.M.
Ferrosilicon	2	2	0	12.32 P.M.
Ferrochrome	10	3	0	12.50 ,,
Ferromanganese	2	2	0	12.57 ,,

(No ladle additions)

Analysis of Ladle Sample

C, %.	Mn, %.	S, %.	P, %.	Si, %.	Ni, %.	Cr, %.
0·58	0·44	0·034	0·040	0·25	2·70	2·02

Pitside Remarks

47 ingots with hot tops, at $8\frac{1}{2}$ cwt. each. ...	19 tons 19 cwt. 2 qr. 0 lb.
Size of nozzle	$\frac{3}{4}$ in. dia.
Ladle skull	Nil

The procedure successfully adopted as standard practice is as follows:

(i) Just before charging the furnace, foundry moulding sand or river sand is shovelled all over the front, back, and end banks.

(ii) A weighed amount of petroleum coke is then spread over the bottom of the furnace. The weight of petroleum coke is adjusted according to the chemical specification of the heat to be made, the object being to obtain about 0·50–0·60% more carbon in the melted charge than is required in the finished steel.

(iii) Immediately the petroleum coke has been charged it is covered over with steel turnings or light steel scrap, after which the heavier steel scrap is charged. The process is speeded up by the use of high-carbon steel scrap and turnings, which must, of course, be sufficiently low in phosphorus and sulphur contents.

(iv) A little time before the melting of the charge is complete, a quantity of acid finishing slag from previous heats is added to the bath. The quantity of slag added at this stage of the process is usually $2\frac{1}{2}$% of the weight of scrap charged.

(v) Further additions of acid finishing slag are made during the working of the heat, as found necessary by the appearance of the slag in the furnace and of the slag and steel samples taken periodically from the furnace. The same consistency and composition of the finishing slag are aimed at as in the normal pig-and-scrap process, and therefore a little limestone is also added as required.

(vi) To compensate for the deficiency of manganese in the charge, manganese ore instead of iron ore is added during the working of the heat to remove the carbon to the desired extent. In an acid furnace the sum of the $FeO + MnO + CaO$ in the slag is practically constant. Therefore an increase of MnO in the slag is desirable, for its presence enables a lower FeO content to be carried in the slag, resulting in a more highly deoxidized steel.

The history of a typical charge is given as an example in Table I.

As there is no anthracite coal available in India, petroleum coke from the Assam oil-fields was chosen as being the most suitable indigenous material for supplying carbon to the charge. Such coke contains only a trace of phosphorus and very little ash. The following is a typical analysis of the petroleum coke used:

Ash	0·78%
Volatile matter...	15·19%
Fixed carbon	84·03%
Total sulphur	0·603%
Total phosphorus	0·006%
Moisture	1·8%

In practice, all the sulphur from the petroleum coke becomes volatilized, none passing into the steel.

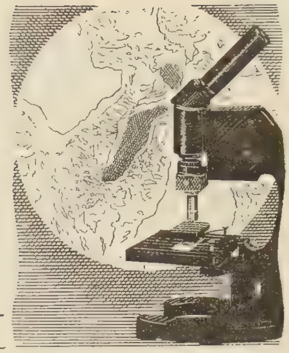
Any composition of steel can be regularly manufactured by the scrap–carbon process described, for as much as 2·54% of carbon has been obtained in the melted charge by this process, and no difficulty has been experienced in obtaining the desired tapping temperature of the steel. A higher yield of ingots from the metal charged is also obtained by the scrap–carbon process in comparison with the usual pig-and-scrap process.

The average time of heats from tap to tap has not increased by the adoption of the scrap–carbon process, and actually has been a few minutes less than by the pig-and-scrap process for the same grade of steel. This is explained by the fact that although a longer time is required to melt 100% scrap as compared with a mixture of pig and scrap, it so happens that in the scrap–carbon process the bath comes to a boil by the time the charge is melted, owing to there being very little silicon and manganese in the charge. Thus the dead-melted condition is seldom observed, and therefore the extra time taken to melt the charge is recovered in working the heat after the charge is melted.

It has generally been accepted that it is impossible to operate the acid open-hearth furnace continuously with charges of 100% steel scrap and produce high-grade qualities of steel thereby, particularly alloy steel. Nevertheless, the process as adopted in India has been so successful for all classes of steel required, and the products have been so satisfactory, that it is unlikely that the pig-and-scrap process will be reverted to when hematite pig iron is again available, so long as a sufficient supply of low-phosphorus and low-sulphur scrap is readily obtainable in India, because of the very high price of imported hematite pig iron in comparison with that of the best quality of steel scrap.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



The Determination of Hydrogen in Liquid Steel*

By J. E. Wells, B.Sc., A.R.I.C., A.Met.,† and K. C. Barraclough, B.Sc., F.R.I.C., A.Met., A.I.M.†

SYNOPSIS

A detailed account is given of five methods of sampling the liquid-steel bath which have been used at the Brown-Firth Research Laboratories for the determination of the hydrogen content of liquid steel ; these methods include the use of a water-chilled mould, a cast-iron chill mould, and an ingot sample, in addition to the balloon-tube and notched-pencil methods described by Hatfield and Newell. The methods are compared on different types of steel and conclusions are drawn as to the reliability and applicability of the methods. The best and simplest method appears to be a modified pencil test in which the sample is taken as soon as possible from the mould and then quenched in water.

INTRODUCTION

THE problem of the determination of the hydrogen content of liquid steel has been much simplified since the advent of the simple and accurate method described by Newell[1] for the determination of hydrogen in solid steel. This method involves measurement of the amount of hydrogen evolved by heating the steel sample *in vacuo* at a temperature of 600° C. Experimental work has therefore been directed towards obtaining a suitable solid sample containing the whole of the hydrogen originally present in the liquid steel. It is well known that hydrogen is more rapidly evolved from steel at elevated temperatures than at room temperature. At this lower temperature the rate of hydrogen evolution is small. It appears reasonable, therefore, that if a sample of liquid steel is rapidly chilled to room temperature and its hydrogen content is determined as quickly as possible, a satisfactory estimate of the hydrogen content of the liquid steel would be obtained, provided that no evolution of hydrogen occurred during solidification of the metal. The results found on samples obtained using chill moulds have been compared, directly or indirectly, with those obtained by the balloon-tube method,[2] as this method also takes account of the hydrogen evolved during solidification and subsequent cooling.

VACUUM-HEATING APPARATUS

Two forms of vacuum-heating apparatus for the determination of the hydrogen content of the steel samples are in use, one for small samples $\frac{1}{2}$ in. long by $\frac{1}{2}$ in. dia., such as are obtained by

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† The Brown-Firth Research Laboratories, Sheffield.

the balloon-tube and notched-pencil methods, and the other for handling the larger samples obtained by the other sampling methods.

When ½-in. samples are used the hydrogen content of a low-alloy steel can be determined in about 1 hr. With austenitic steels of the 18/8 type, up to 3 hr. may be necessary.

With larger samples the time required is correspondingly longer. The largest sample used, a 3-in. dia. cylinder 3 in. long, requires a period of 5–6 hr. in the case of a low-alloy steel.

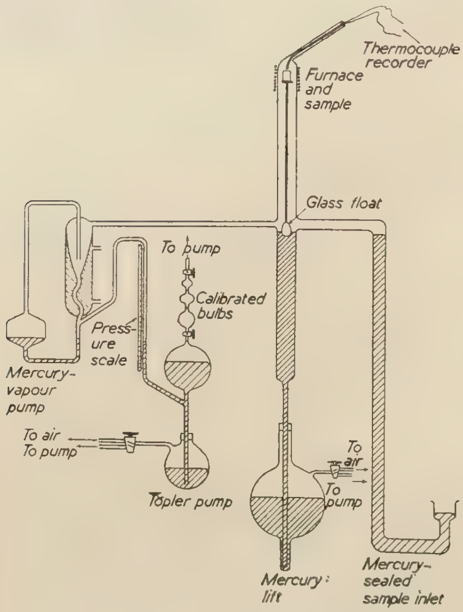

FIG. 1—Apparatus for determination of hydrogen content of small samples

(a) *Apparatus for Determination of Hydrogen Content of Small Samples*

This apparatus is shown diagrammatically in Fig. 1, a photograph appearing in Fig. 5. It is a slightly modified form of that described by Newell.[1] The sample tubes have been replaced by a " mercury lift " open to the atmosphere at one end ; this device enables samples to be introduced into, or withdrawn from, the apparatus without breaking the vacuum, thus cutting down the interval between taking the sample and the determination of its hydrogen content. The remainder of the apparatus is unchanged, as is the method of use. The sample is heated *in vacuo* to 600° C. and the gas evolved is compressed by means of the mercury-vapour and Töpler pumps into the calibrated bulbs, the pressure being measured. The gas may then be analysed by transferring to an Ambler-type gas-analysis apparatus.

(b) *Apparatus for Determination of Hydrogen Content of Large Samples*

This apparatus is illustrated in Figs. 2 and 6. The furnace chamber in this case consists of a silica tube 3 in. in internal dia. and about 2 ft. long, the furnace winding occupying the central 5 in. of the tube. The gas is collected in the calibrated gas burette by means of the mercury-vapour and Töpler pumps, and is analysed for its hydrogen content.

METHODS OF SAMPLING LIQUID STEEL

(a) *The Balloon-Tube Method*

The apparatus used is illustrated in Figs. 3 and 7 and has been described by Hatfield and Newell[2] ; it is prepared as follows : A piece of thick-walled mild-steel hydraulic pressure tubing, 9 in. long and ½ in. in bore, is suitably cleaned and dried. One end of the tubing is sealed by soldering to it a piece of clean tinned copper foil. A piece of clean steel rod is pushed into the tube, leaving a ½-in. space at the closed end. This rod must be sufficiently tight not to slip when fixed, but must allow free passage of gas up the tube ; its function is to decrease the dead space of the apparatus. A glass **T**-piece, carrying a toy balloon and a short length of rubber pressure tubing, is fitted to the other end of the steel tube. The apparatus is evacuated and tested for freedom from leaks ; if satisfactory it is filled with dry nitrogen, the balloon being left in a collapsed condition and the rubber tube closed by means of a screw clip.

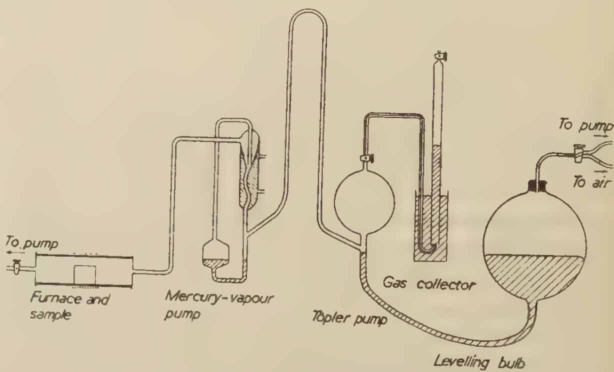

FIG. 2—Apparatus for determination of hydrogen content of large samples

In order to obtain a sample a sample spoon is " slagged " and a spoonful of metal withdrawn from the furnace. After skimming-off any slag and killing the steel with aluminium, the lower end of the balloon tube is immersed in the molten

netal to a depth of about 1 in., held for 4 sec., nd slowly withdrawn. After cooling, the end of he tube is immersed in water or mercury, which ffectively prevents leakage if the sample has not ealed perfectly round the end of the tube. Any gas collected is drawn off into the gas-analysis pparatus and analysed. The $\frac{1}{2}$-in. steel sample s removed from the tube, lightly surface-ground o remove scale, and cleaned in ether. Its ydrogen content is then determined by vacuum eating, the total hydrogen content of the liquid teel being obtained by adding the amount found n the gas to that found in the solid sample.

b) *The Notched-Pencil Method*

The mould used, together with the type of est-piece obtained, was described by Hatfield nd Newell,[2] and is shown in Fig. 8. The ample is obtained by filling the mould from a poon sample taken as before. On opening-up he mould, the sample, which is about $\frac{1}{2}$ in. in dia. vith notches every $\frac{1}{2}$ in. of its length, can be emoved and a suitable sample broken off. This s then freed from scale, &c., as before, and its ydrogen content determined.

c) *The Water-Chilled-Mould Method*

The mould in this case is in the form of a runcated cone 2 in. in dia. at the open top,

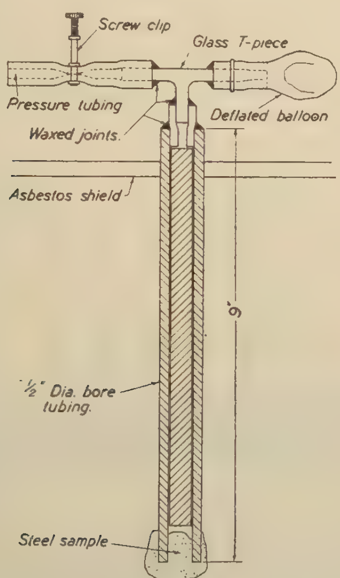

FIG. 3—The balloon-tube method of sampling liquid steel

1½ in. in dia. at the bottom, and about 5 in. deep. The walls are made of $\frac{1}{16}$-in. mild-steel sheet, the base being $\frac{1}{8}$ in. thick. A large flange is fitted to the top, and all the joints are welded. The mould is illustrated in Fig. 7.

Before taking the sample the mould is dried out and then placed in a container almost full of water, the flange covering the top of the container. The mould is then half-filled from a spoonful of

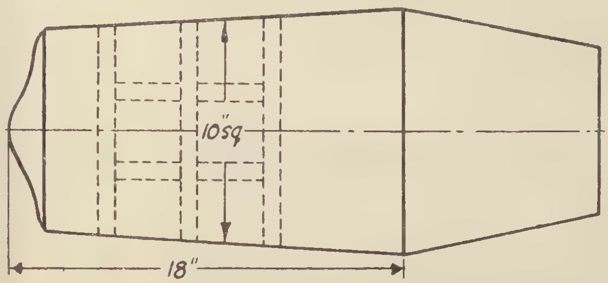

FIG. 4—Method of sectioning ingot to obtain ingot sample; 5-cwt. ingot producing two core samples $2\frac{3}{4}$ in. in dia. and 3 in. long

steel taken as before. When cool, the sample is cleaned as before and its hydrogen content determined in the large apparatus. The type of sample obtained can be seen in Fig. 6.

(d) *The Cast-Iron-Chill-Mould Method*

The mould is illustrated in Fig. 7. It consists of a cylinder of cast iron, 6 in. in dia. and 4 in. deep, fitted with two lugs. In the centre is machined a hole, $1\frac{1}{2}$ in. deep, $1\frac{1}{2}$ in. in dia. at the bottom, and 2 in. in dia. at the top. The hole is filled with liquid steel from a sample taken in the usual way, and the sample so obtained allowed to cool. The hydrogen content is determined as in the water-chilled-mould method. The type of sample obtained is shown in Fig. 6.

(e) *The Ingot Sample*

A 5-cwt. ingot, cast at the same time as the other ingots in the heat, is sectioned as shown in Fig. 4 to produce two samples, $2\frac{3}{4}$ in. in dia. and 3 in. long, illustrated in Fig. 6. This machining is carried out with a minimum of delay and the hydrogen content of the resultant samples is determined in the large apparatus.

In all cases hydrogen determinations are made as soon as possible after sampling. When delay is unavoidable the samples are kept in solid carbon dioxide, as at the low temperature of this material the rate of hydrogen evolution is much diminished.

The following experiments were conducted to determine the effect of this form of storage. Cylinders of pure iron, $\frac{1}{2}$ in. long by $\frac{1}{2}$ in. in dia., were heated in a stream of hydrogen for 2 hr.

TABLE I—*Preliminary Results*

Cast No.	Type of Steel.	Pencil Test.		Balloon Test. Total		Balloon Test. Metal		Water-Chill Test.		Cast-Iron-Chill Test.		Ingot Sample.	
		H_2, %.	H_2, ml./100 g.	H_2, %.	H_2, ml./100 g.	H_2, %.	H_2, ml./100 g.	H_2, %.	H_2, ml./100 g.	H_2, %.	H_2, ml./100 g.	H_2, %.	H_2, ml./100 g.
1	Cr–Mo (B.E.)	0·00051 ...	5·7 ...	0·00058 0·00054	6·5 6·1	0·00047 0·00047	5·3 5·3	0·00063 ...	7·1 ...	... ...	... ...	0·00059* ...	6·6 ...
2	Cr–Mo (A.O.H.) ...	0·00036	4·0	...	...	...	...	...	...	0·00049	5·5	...	...
3	Cr–Mo (B.E.)	0·00077	8·6	0·00077	8·6	0·00077	8·6	0·00068	7·6	...	...	0·00074†	8·3
4	Ni–Cr–Mo (B.E.) ...	0·00073 ...	8·2 ...	... ...	... ...	0·00062 0·00069	6·9 7·7	0·00069 ...	7·7 ...	... ...	... ...	... ...	... ...
5	Ni–Cr–Mo (A.O.H.) ...	0·00026 ...	2·9 ...	0·00041 0·00043	4·6 4·8	0·00033 0·00041	3·7 4·6	0·00030 ...	3·4 ...	... ...	... ...	0·00038* 0·00044	4·3 4·9
6	Ni–Cr–Mo–V (A.O.H.)	0·00044	4·9	...	...	...	...	0·00038	4·3	0·00037	4·1	...	...
7	3½% Ni (B.E.) ...	0·00052	5·8	...	...	...	...	0·00045	5·0	...	...	...	...
8	3½% Ni (B.E.) ...	0·00053 ...	5·9 ...	... ...	... ...	0·00046 0·00048	5·2 5·4	0·00063 ...	7·1 ...	... ...	... ...	0·00058 0·00059	6·5 6·6
9	5% Ni–Mo (B.E.) ...	0·00040	4·5	...	...	0·00045	5·1	0·00036	4·0	...	...	...	...
10	5% Ni–Mo (B.E.) ...	0·00053 ...	5·9 ...	0·00051 ...	5·7 ...	0·00048 ...	5·4 ...	0·00057 ...	6·4 ...	... ...	... ...	0·00059 0·00057	6·6 6·4
11	0·2% C (A.O.H.) ...	0·00045 ...	5·0 ...	... ...	... ...	... ...	... ...	0·00043 ...	4·8 ...	0·00030 ...	3·4 ...	0·00049 0·00050	5·5 5·6
12	0·3% C (B.E.) ...	0·00056	6·3	...	...	...	...	0·00066	7·4	0·00058	6·5	...	...
13	13% Cr (A.H.F.) ...	0·00059	6·6	...	...	...	...	...	...	0·00051	5·7	...	...
14	3½% Ni (B.E.) ...	0·00050	5·6	...	...	...	...	0·00061	6·8	...	...	...	...
15	Cr–Mo (B.E.)	0·00082	9·2	...	...	...	...	0·00120	13·4	0·00077	8·6	...	...
16	18/8 (B.E.)	0·00070	7·8	...	...	...	...	0·00069	7·7	0·00069	7·7	...	...

B.E. = Basic electric-arc ; A.O.H. = Acid open-hearth ; A.H.F. = Acid high-frequency.

* The ingot from this cast was given the following annealing treatment before sectioning : Held 4 hr. at 350° C. ; heated to 650° C. ; held 6 hr. at 650° C. and air-cooled.

† The ingot from this cast was given the following annealing treatment before sectioning : Held 2 hr. at 500° C. ; heated to 720° C. ; held 6 hr. at 720° C. and air-cooled.

The remaining ingots were sectioned in the as-cast state.

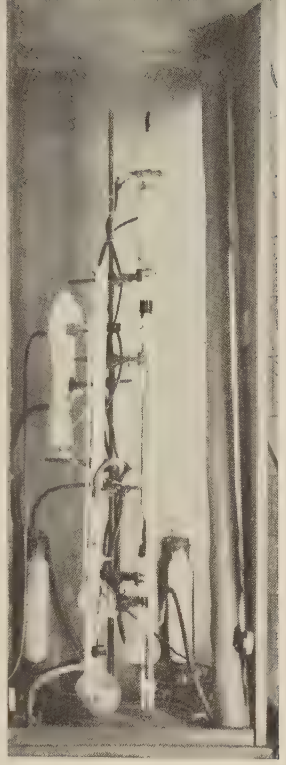

FIG. 5—Apparatus for determination of hydrogen content of small samples

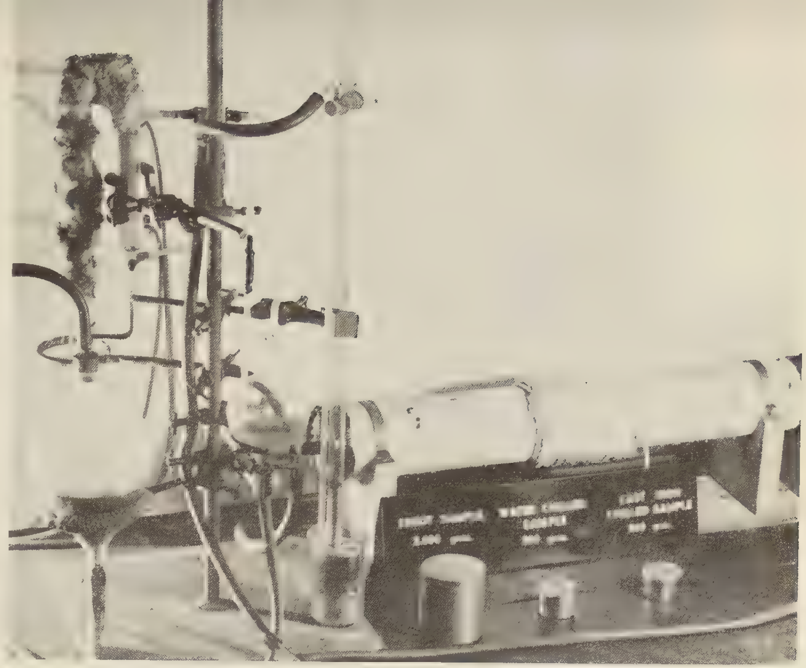

FIG. 6—Apparatus and type of samples used for determination of hydrogen content of large samples

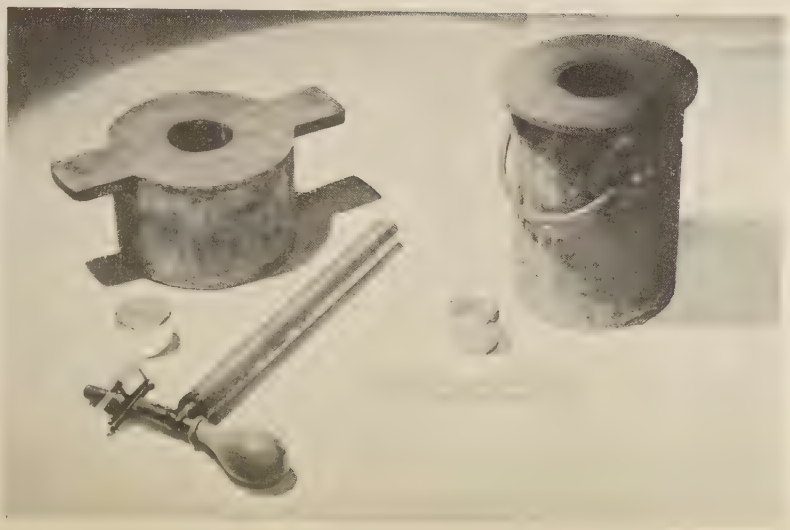

FIG. 7—Cast-iron chill mould, balloon tube, and water-chilled mould in container

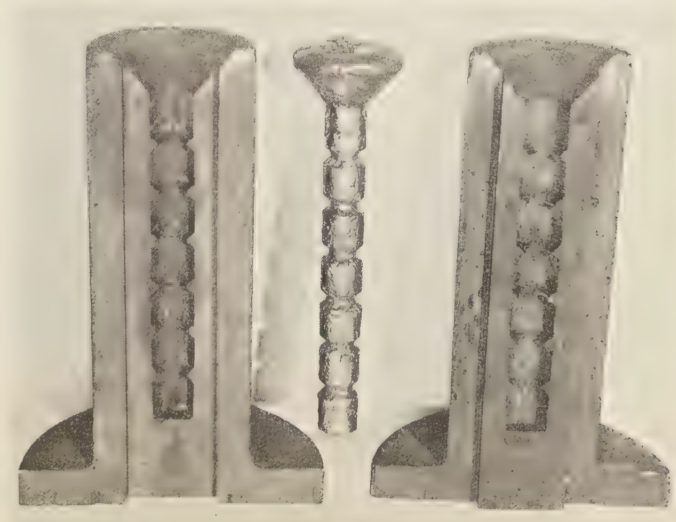

FIG. 8—Notched-pencil mould and sample

TABLE II—*Results Obtained on Water-Quenched Samples*

Cast No.	Type of Steel.	Pencil Test.		Water-Chill Test.		Ingot Sample.†	
		H_2, %.	H_2, ml./100 g.	H_2, %.	H_2, ml./100 g.	H_2, %.	H_2, ml./100 g.
17	Cr–Mo (B.E.) ...	0·00056 0·00053	6·3 5·9	0·00049	5·5	...	...
18	3½% Ni (B.E.) ...	0·00044	4·9	0·00040	4·5	...	...
19	Cr–Mo (B.E.) ...	0·00060	6·7	0·00060	6·7	...	...
20	Cr–Mo (B.E.) ...	0·00049	5·5	0·00054	6·1	...	...
21	C–Mo (B.E.)	0·00043	4·8	...	...	0·00041	4·6
22	Ni–Cr–Mo (B.E.) ...	0·00046	5·2	0·00040	4·5	0·00043	4·8
23	C–Cr (B.E.)	0·00040	4·5	0·00035	3·9	...	...
24	C–Mo (B.E.)	0·00035 0·00032	3·9 3·6	... ...	... ...	... ...	... ...
25	Cr–Mo (B.E.) ...	0·00069 0·00070	7·7 7·8	... ...	... ...	... ...	... ...
26	C–Cr (B.E.)	0·00037 0·00040	4·2 4·5	... ...	... ...	... ...	... ...
27	13% Cr (B.E.) ...	0·00052	5·8	...	...	...	...
28*	13% Cr (B.E.) ...	0·00147 0·00149	16·5 16·7	... ...	... ...	... ...	... ...

B.E. = Basic electric-arc.

* This sample was taken from a heat made with wet ferrochromium. As expected, the ingots were "wild," but the pencil test was perfectly sound after water-quenching. This example has been included to show that large quantities of hydrogen can be held in the pencil test by the treatment outlined. A normal 13% chromium steel is included for comparison, (Cast No. 27).

† The ingot from cast No. 22 was given the following annealing treatment before sectioning : Held 4 hr. at 300° C. ; heated to 650° C. ; held 6 hr. at 650° C. and air-cooled. The ingot sample from cast No. 21 was sectioned in the as-cast state.

at 1100° C. and were then water-quenched. Various treatments were given to individual cylinders and the hydrogen contents were determined, with the following results :

Treatment.	Hydrogen, %.
Tested immediately	0·00051
Stored 4 days in solid CO_2	0·00046
Stored 17 days in solid CO_2 ...	0·00042
Stored 4 days at room temperature ...	0·00029
Maintained 18 hr. at 100° C. ...	0·00017

Further evidence of the retention of the hydrogen by storing the sample in solid carbon dioxide has been obtained by testing portions of pencil tests after leaving overnight in the solid carbon dioxide container. The results were as follows :

Steel.	Hydrogen, %, tested immediately.	Hydrogen, %, after storage in solid CO_2.
Cr–Mo ...	0·00069	0·00070 (24 hr.)
C–Mo ...	0·00035	0·00032 (48 hr.)
13% Cr ...	0·00147	0·00149 (18 hr.)

PRELIMINARY RESULTS

Samples were taken from a number of heats, using two or more of the methods described. In each case the ingot sample was taken during casting, the other samples being taken just before tapping. The results obtained are shown in Table I.

The agreement shown by the different methods of sampling was encouraging. In general the balloon-tube sample, the ingot sample, and the water-chill sample gave results which agreed well with one another. On the other hand the tendency was for the pencil test and the cast-iron-chill test to give lower results. In view of the relatively good results given by the water-chill test it was decided to discontinue the use of the cast-iron chill mould and to concentrate on improving the water-chill and pencil tests, particularly the latter, as a reliable pencil test would

enable results to be obtained more rapidly.

It was noted in the course of this work that the skin temperature of the water-chilled-mould sample during cooling appeared lower than that of the cast-iron-chill test-piece made at the same time; this is to be expected, since the water in the container cannot do more than boil, whereas the cast-iron mould in contact with the sample can reach a much higher temperature. The temperature of the centre of the water-chilled sample, however, appeared to be higher than that of the cast-iron-chill sample. This must be an optical illusion. On any type of chilled sample the cooling rate must become less as the sample temperature drops, owing to a fall in the temperature gradient between the sample and the mould. It appears probable that, with the hydrogen contents usually obtained in steel, the hydrogen solubility under 1-atm. pressure is not exceeded until the steel cools to a temperature around 1100° C. or below. Until this occurs there is less tendency for hydrogen to escape in the small time allowed for cooling. When the solubility is exceeded, however—unless the sample is rapidly cooled, for example, by water-quenching—there is a much greater opportunity for the hydrogen to escape. It was therefore decided to investigate the effect of increasing the rate of cooling in the lower temperature range by water-quenching the various types of sample while they were still at a red heat. Quenching from a higher temperature is difficult, owing to the high cooling rate in the moulds. The danger of introducing an error owing to hydrogen pick-up by water-quenching the samples in this way was investigated. It was found that the water-quenching of samples of vacuum-treated, and thus hydrogen-free, steel from temperatures between 650° C. and 1150° C. introduced a maximum of 0·00001% of hydrogen, which is within the limit of the normal experimental error.

A modification in sampling technique was thus evolved: All samples were taken from the moulds as soon as possible after solidification and were immediately water-quenched. With this procedure a pencil test can be cooled from liquid-steel temperatures to about 20° C. in about 20 sec. The samples so obtained are placed in solid carbon dioxide until their hydrogen content can be determined.

Results on Water-Quenched Samples

The results obtained on samples which were water-quenched in this manner are given in Table II. It will be seen that the methods agree very well when the modified sampling technique is used, the pencil test giving slightly higher results than the other methods of sampling.

It has been found that a small decrease in hydrogen content occurs on tapping the steel,* as shown by the following figures, which are derived from pencil tests taken from the furnace before tapping and from the ladle immediately after tapping:

	Before Tapping.		After Tapping.	
Steel.	Hydrogen, %.	Hydrogen, ml./100 g.	Hydrogen, %.	Hydrogen, ml./100 g.
Ni–Cr–Mo	0·00040	4·5	0·00033	3·7
Ni–Cr–Mo	0·00045	5·1	0·00037	4·2
0·2% C.	0·00053	5·9	0·00049	5·5

It is to be expected, therefore, that the ingot sample taken after tapping should show a slightly lower hydrogen content than the water-quenched pencil-test sample taken from the furnace before tapping.

Conclusions

In view of the degree of agreement obtained between the very different methods of sampling, and the wide variation found between the hydrogen contents of the different heats examined, it is reasonable to conclude that the methods described give a satisfactory estimate of the hydrogen content of liquid steel.

The pencil test with the modified method of sampling (namely, quick stripping from the mould followed by water-quenching) gives a rapid and reasonably accurate method for the determination of the hydrogen content of liquid steel; an estimate of the hydrogen content can be obtained in 1 hr. when this method is used on a ferritic steel, although up to 3 hr. may be necessary for a similar determination on an austenitic steel. This pencil test should prove to be of great value in metallurgical investigations.

Acknowledgments

This work was carried out in the Brown-Firth Research Laboratories and the authors are indebted to Dr. C. Sykes, F.R.S., for his personal interest in the investigation.

The authors thank Mr. C. C. Gegg for his valuable help in the control of the various ingot samples, and also the melting-shop staff of Messrs. Thos. Firth and John Brown, Ltd., for their interest and assistance.

References

1. W. C. Newell: *Journal of the Iron and Steel Institute*, 1940, No. I., p. 243 P.
2. W. H. Hatfield and W. C. Newell: *Journal of the Iron and Steel Institute*, 1943, No. II., p. 407 P.

* Cases have been reported where a large increase in hydrogen content has occurred on tapping. This is presumably owing to incomplete drying of the refractory lining of the ladle.

First Report of the Side-Blown Converter Practice Sub-Committee*

OF THE STEEL CASTINGS RESEARCH COMMITTEE

SYNOPSIS

Detailed records have been taken of side-blown converter heats from plants of varying design and operating technique. The records have been studied with regard to the composition of metal and slag at various stages of the blow, the temperature increment during the blow, the composition of the exit gas, the effect of variation in tuyere area, the metal loss during blowing, and the quality of the steel as judged by the content of the exit gases.

There appears to be a marked similarity between the acid side-blown converter process and the acid open-hearth process in that the reactions are mainly between metal and slag, and the resulting steels have similar properties.

A calculated heat balance also shows good comparison with that of the open-hearth process as regards thermal efficiency.

INTRODUCTION

THE Sub-Committee was formed in September, 1943, at a meeting of representatives of four firms using side-blown converters and members of the Iron and Steel Control.

The object was to study the practice at each works, with a view to improving such practice, bearing in mind the necessity for conservation of raw materials and maximum output from available plant. As refractory problems would be introduced, a separate Panel was formed to deal with them, and this aspect will be reported upon separately.

The Sub-Committee was affiliated to the Steel Castings Research Committee of the Iron and Steel Institute in November, 1943, with the following membership :

Dr. T. P. COLCLOUGH (*Chairman*),
Iron and Steel Control.

Mr. B. L. COLLINS,
Messrs. Samuel Osbourn & Co., Ltd.

Mr. F. COUSANS,
Messrs. Thos. Firth and John Brown, Ltd., later, Messrs. Catton & Co., Ltd.

Dr. A. H. B. CROSS,
The Brown-Firth Research Laboratories.

Mr. S. T. JAZWINSKY,
K. and L. Steelfounders and Engineers, Ltd.

Mr. W. ROUTLEDGE,
Stanton Ironworks Co., Ltd.

Mr. T. H. SKELTON,
Messrs. Edgar Allen & Co., Ltd.

Mr. S. SPRAY (*Secretary*),
Stanton Ironworks Co., Ltd.

Mr. W. W. STEVENSON,
The United Steel Companies, Ltd.

Dr. T. SWINDEN (*Obit.*),
The United Steel Companies, Ltd.

Mr. J. D. TOWNSEND,
Stanton Ironworks Co., Ltd., later, Messrs. Thos. Firth and John Brown, Ltd.

In addition the following have attended occasional meetings by invitation : Dr. E. Gregory (Edgar Allen & Co., Ltd.), Mr. P. C. Fassotte (Iron and Steel Control).

SCOPE OF THE FIRST REPORT

The Report represents the result of the work to date. The preliminary conclusions reached serve mainly to emphasize the limitations of production units used for experimental purposes and the need for a converter plant which can be

* Paper No. 21/1946 submitted by the Side-Blown Converter Practice Sub-Committee of the Steel Castings Research Committee, received 5th February, 1946.

used for the detailed study of outstanding metallurgical and refractory problems.

The Report is divided into the following parts :

PART I

(a) *Existing Practice in Converter Design and Operation.*

(b) *Details of Typical Heats.*

PART II—EXPERIMENTAL WORK

(a) *Analysis of Metal and Slag at various Stages of the Process under varying Conditions.*

(b) *Temperature Increment Obtainable from Metal under various Conditions.*

(c) *Analysis of the Exit Gas from the Converter.*

(d) *Investigation of Chemical and Mechanical Conversion Loss.*

(e) *Investigation of Tuyere Arrangement and Air Supply.*

PART III—HEAT BALANCE OF THE SIDE-BLOWN CONVERTER PROCESS

PART IV—CONCLUSIONS AND RECOMMENDATIONS

PART I

(a) *Existing Practice in Converter Design and Operation*

The investigations have been carried out in the works of four firms which are designated as *A*, *B*, *C*, and *D*. The melting plants in these works all differ, and as some of their features have a bearing on the results of the investigations, the essential characteristics of these plants are given below.

A. Cupolas with shallow wells and fitted with receivers, resulting in low carbon iron. Relatively short converters with consequent blast volume, fitted with " Robert " tuyere arrangement. Blowers of ample capacity.

B. Cupolas of normal design. Converters of more recent construction and with longer bodies than in Plant *A*. High-pressure blowers, but without any margin of capacity.

C. Cupolas of normal design. Converters originally of small capacity (30 cwt.). To increase their capacity, the vessels were lengthened and the bath made considerably deeper than average. Blowers ample.

D. The plant is composed of cupolas, rotary furnaces, and converters. The low silicon iron produced by the cupolas is superheated in the rotary furnaces before conversion. Converters are of similar design to those in Plant *B*, and the blowers are of ample capacity.

Figure 1 shows the principal features of the converter bodies used in the four plants, and the differences in the average steel-making practice used in these plants become apparent from a study of Tables I and II.

The vessel construction at all works was in silica brick throughout, with the exception of Plant *D*, where the nose was monolithic.

Apart from overall sizes, the chief differences to be noted are the variation in the ratios of cross-sectional area to depth of well, to tuyere area,

TABLE I—*Details of Plant Design*

Plant.	*A.*	*B.*	*C.*	*D.*
Nominal capacity of vessel, cwt. ...	60	47	50	55
Shape of vessel	D-shape	D-shape	Circular	Approximately circular
No. of tuyeres	7	5	7	6
Dia. of tuyeres, in.	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{3}{4}$
Capacity/tuyere area, cwt./sq. in. ...	0·28	0·19	0·21	0·26
Tuyere area, sq. in.	16·8	8·8	10·4	14·4
Arrangement of tuyeres	6 inclined, 1 straight	At right angles to tuyere box	At right angles to tuyere box	At right angles to tuyere box
Depth of well	1 ft. 10 in.	1 ft. 0 in.	2 ft. $1\frac{1}{2}$ in.	1 ft. 7 in.
Area at tuyere level, sq. in.	1250	1134	755	1250
Area/capacity ratio, sq. in./cwt. ...	21	24	15	23
Area/depth of well ratio	57 : 1	94 : 1	30 : 1	66 : 1
Area/tuyere area ratio	75 : 1	130 : 1	72 : 1	87 : 1
Type of blower	Rotary	Compressor	Rotary	Rotary
Maximum output of blower, cu.ft./min.	4380	2500	2400	5000

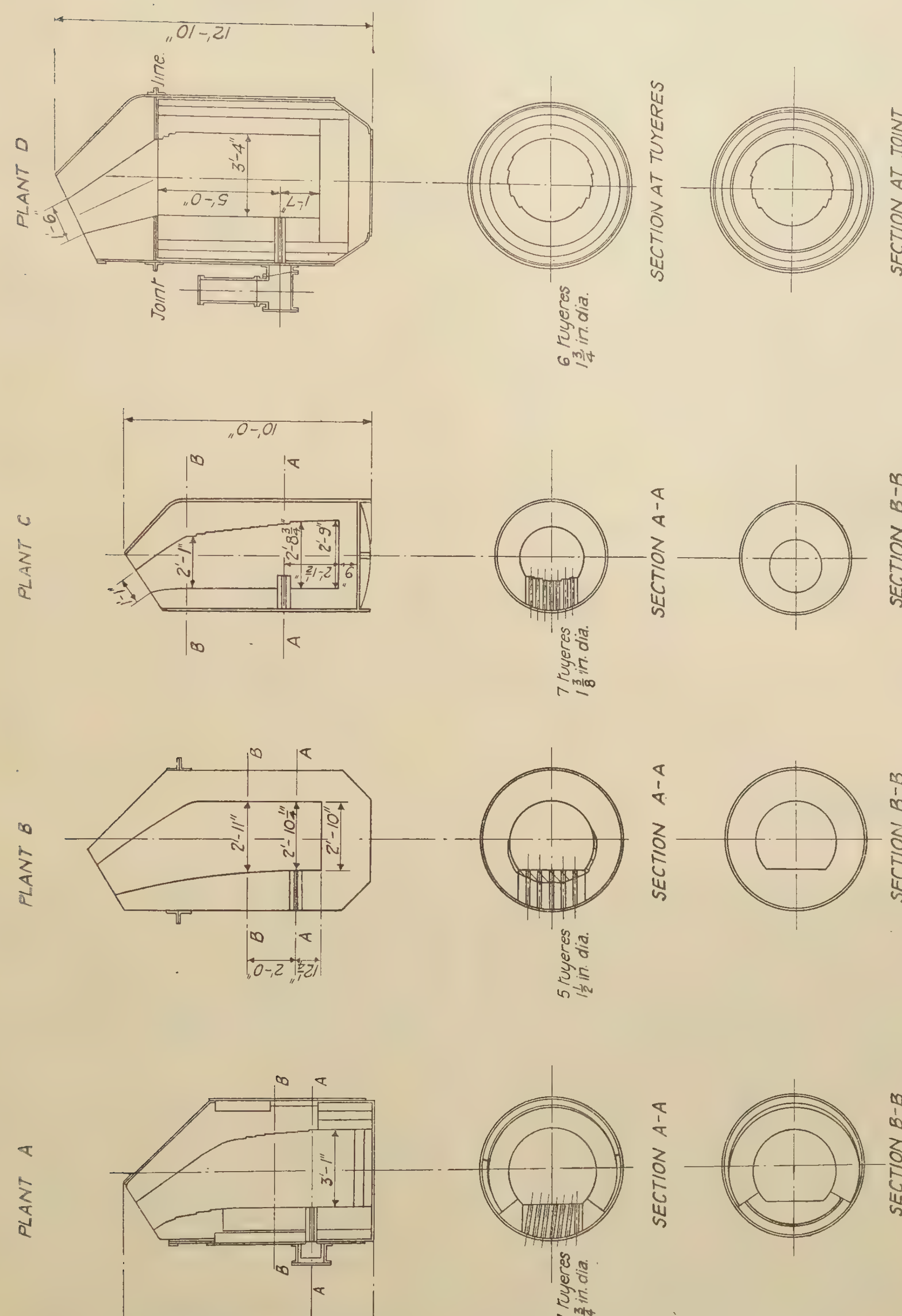

FIG. 1—Sectional drawings of converters

Table II—*Average Converter Operating Conditions*

Plant.	*A.*	*B.*	*C.*	*D.*
Composition of metal charged :				
Carbon, %	2·5	3·3	3·0	3·1
Silicon, %	1·0	1·0	1·2	0·1
Manganese, %	0·3	0·4	0·4	0·4
Sulphur, %	0·06	0·04	0·03	0·04
Phosphorus, %	0·04	0·04	0·05	0·06
Temperature, ° C.	1320	1300	1320	1450
Blast volume, cu. ft./min. ...	2400–2800	2200	1600–1800	3500
Blast pressure, lbs./sq. in. ...	3	5	4	4
Blowing time, min.	25	19–20	30	9–12
Blowing angle, deg.	20–10	14–10	20–12	13–8
Additions during blow :				
Ferrosilicon, lb.	80	12	60	20
Silicon content of ferrosilicon, %	75	75	45	75
Resultant silicon increase in steel, %	0·9	0·2	0·5	0·25
Deoxidation and alloying ...	Metal poured into a ladle containing 6 lb. per ton Al, then into a second ladle containing 1–1½ lbs. per ton Ca, Si, Mn, and alloys.	Slag raked off; 7 lb. per ton Al rabbled in. Alloys thrown into vessel.	Ferrosilicon, silicon – manganese and ferromanganese added in vessel. Then poured into a ladle containing 3 lb. per ton Al.	Slag raked off; 5 lb. per ton Al rabbled in. Alloys thrown into vessel.
Interval between heats (blast off to blast on), min. ...	30	15	30	5

and to capacity. In these respects the converters at Plants *A* and *D* are similar to each other but they differ widely from those at Plants *B* and *C*.

The converter operating conditions for the production of carbon–manganese steel (C, 0·2–0·25%, Mn, 1·4–1·6%) are given in Table II.

A point of similarity in plants *A*, *B*, and *C* is that hematite pig is used in the cupola charge; 50% in Plant *A*, and up to 30% in Plants *B* and *C*. In plant *D*, 100% steel scrap is melted in the cupola, and a rotary furnace is used to superheat the metal before charging into the converter. On this account the latter has advantages in the conservation of hematite iron and also it can yield a bigger output from a given capacity on account of the greatly reduced blowing time required, due to the use of high carbon, low silicon, superheated metal in the converter. It will be noted that the blast pressure varied inversely as the tuyere area.

A difference in the practice at Plant *D* compared with the others is in the use of sand which, added in the vessel before it receives the charge, provides an acid oxide to combine with the large quantities of iron oxide produced in the early stages of the blow. This practice resulted in considerable improvement in the life of the lining.

The blowing angle is reduced during the blow, as shown in Table II. It is recorded as degrees from the vertical.

Other features are the differences in blast pressure, blowing time, and metal composition. Considerable space is given later in the Report to the effect on the temperature increment of carbon and silicon, but it is interesting to note here, that as a result of practical experience, the addition of ferrosilicon is much greater with low carbon metal.

(b) *Details of Typical Heats*

Before commencing any experimental work in the plants represented by various members of the Sub-Committee, it was considered desirable

	Plant A.						Plant B.					Plant C.				Plant D.			
	Type of Addition.	Heat No. 1	2	3	4	5	Type of Addition.	Heat No. 1	2	4	6	Type of Addition.	Heat No. 4	5	6	Type of Addition.	Heat No. 1	2	3
Analysis of metal charged :																			
Carbon, %		2·82	2·74	2·34	2·48	2·52		3·38	3·25	3·16	3·24		3·21	2·36	3·00		2·92	3·14	2·98
Silicon, %		0·71	0·60	0·88	0·77	1·02		1·08	1·13	1·13	1·08		1·13	0·78	1·39		0·10	0·14	0·13
Manganese, %		0·34	0·22	0·36	0·31	0·26		0·24	0·49	0·48	0·34		0·43	0·35	0·41		0·43	0·47	0·34
Sulphur, %		0·035	0·036	0·038	0·072	0·064		0·045	0·041	0·038	0·04		0·034	0·032	0·021		0·036	0·055	0·029
Phosphorus, %		0·051	0·057	0·059	0·043	0·037		0·031	0·040	0·047	0·037		0·038	0·038	0·041		0·057	...	0·056
Vessel temp. before blow (optical pyrometer), ° C.		1200	1240	1280	1290	1250		1470	1375	1500	1480		...	...	...		1410	1390	1460
Metal temp. as poured to vessel (immersion pyrometer), ° C. ...		1270	1290	1310	1320	1300		1322	1318	1276	1263		1332	1294	1314		...	1430	1370
Wt. of Metal, lb.		6608	7056	7392	7840	7728		5068	5124	5404	5124		6160	5992	6288		6288	6288	6720
Duration of blow, min.		30	30	29	22	26		23	19	21	19		27	26	35		11	11	11
Blowing angle, deg.		16–10	20–10	14–6	20–6	12–6		14–12	12–10	12–9	4–1		22–12	20	27–16		13	11–10	10–7
Air pressure, lb./sq. in.		3·25–3·1	2·8–2·2	3·2–2·7	2·9–1·7	4·0–2·0		5·5–3·5	5·5–2·75	5·0–3·5	4·0–2·0		4·21–3·75	4·1–3·8	4·4–4·0		4–3	7–4·8	4–3·5
Blast volume, cu. ft./min. ...		2320–2175	3090–2550	2400–2125	3000–2175	2850–1875		1250–1000	1250–1000	1250–1000	1250–1000		2674–2567	2941–2253	2988–2086		3500–3000	3580–3050	3200–2900
Air humidity, %		32–30	20–19	36–31	36–32	32–30		97	100	80	86		59–56	54–51	62–59		93	68	100
Additions before blow		nil	nil	nil	nil	nil		nil	nil	nil	nil	45% FeSi	24 lb.	nil	16 lb.	75% FeSi Sand	30 lb. 70 lb.	14 lb. 70 lb.	48 lb. 70 lb.
Additions during blow	75% FeSi	100 lb.	140 lb.	96 lb.	70 lb.	70 lb.	75% FeSi	nil	12 lb.	18 lb.	15 lb.	.. ..	nil	32 lb.	nil		nil	nil	nil
Analysis of Blown metal :																			
Carbon, %		0·07	0·09	0·12	0·05	0·04		0·07	0·10	0·08	0·08		0·06	0·07	0·06		0·10	0·08	0·10
Silicon, %		0·10	0·11	0·17	0·05	0·09		0·03	0·05	0·08	0·08		0·02	0·02	0·01		0·02	0·02	0·03
Manganese, %		0·04	0·03	0·06	0·02	0·05		0·01	0·04	0·07	0·03		0·02	0·03	0·02		0·12	0·12	0·05
Sulphur, %		0·025	0·030	0·031	0·061	0·058		0·044	0·036	0·027	0·038		0·033	0·038	0·022		0·044	0·048	...
Phosphorus, %		0·046	0·058	0·056	0·039	0·035		0·035	0·052	0·046	0·045		0·043	0·045	0·049		0·060	0·064	...
Vessel slag at end of blow :																			
SiO_2, %		68·92	69·68	69·50	72·90	71·10		63·67	60·85	59·24	62·00		72·30	64·10	58·00		64·50	64·50	62·00
Al_2O_3, %		3·24	3·66	2·30	2·40	4·56		0·87	1·10	1·10	0·84		6·80	10·50	6·50		4·97	6·00	6·00
FeO, %		18·34	14·76	15·12	} 20·40	} 20·58		22·30	24·10	26·70	26·10	Estimated as FeO	} 17·1	} 21·6	} 30·2	As FeO	} 15·69	} 10·81	} 19·80
Fe_2O_3, %		3·44	5·60	7·20				2·54	2·61	5·32	3·36								
Cr_2O_3, %		...	...	...	...	...		0·63	3·80	1·34	0·94		...	...	...		...	...	...
MnO, %		4·06	1·79	4·49	2·55	2·42		6·94	3·37	4·80	5·35		2·90	3·52	4·70		12·83	16·74	10·78
TiO_2, %		...	...	...	0·47	0·77		0·48	0·43	1·20	0·45		...	...	...		0·20	0·20	0·20
CaO, %		1·32	3·89	1·00	0·80	0·20		0·21	0·14	0·09	0·23		0·66	0·66	0·66		0·40	0·60	0·40
Vessel slag after adding alloys :																			
SiO_2, %		60·96		62·36	Not determined.			Slag removed before adding alloys.					52·00	53·00	54·30		Slag removed before adding alloys.		
Al_2O_3, %		12·16		9·36									8·20	10·80	8·00				
FeO, %		4·90		8·93								Estimated as FeO	} 22·70	} 24·00	} 25·20				
Fe_2O_3, %		14·24		6·88															
MnO, %		4·86		7·38									17·09	11·16	11·91				
TiO_2, %		0·52		0·50									...	...	...				
CaO, %		2·35		4·64									0·66	0·90	0·58				
MgO, %		trace		trace									0·13	0·20	0·07				
Additions to blown metal for deoxidation and alloying.	90% Al	18 lb.	18 lb.	9 lb.	18 lb.	18 lb.	95% Al	nil	nil	14 lb.	14 lb.	Al	4·5 lb.	4·5 lb.	8 lb.	Al	13 lb.	13 lb.	14 lb.
	CaSiMn	5 lb.	5 lb.	5 lb.	5 lb.	5 lb.	78% FeMn	78 lb.	78 lb.	110 lb.	110 lb.	80% FeMn	115 lb.	115 lb.	115 lb.	80% FeMn	90 lb.	90 lb.	100 lb.
	75% FeMn	100 lb.	60 lb.	60 lb.	160 lb.	145 lb.	75% FeSi	21 lb.	21 lb.	15 lb.	15 lb.	13% Si, 68% Mn	30 lb.	30 lb.	30 lb.	SiMn	34 lb.	34 lb.	34 lb.
	75% FeSi	12 lb.	12 lb.	14 lb.	14 lb.	12 lb.						45% FeSi	40 lb.	40 lb.	40 lb.	75% FeSi	10 lb.	10 lb.	10 lb.
Backwall temp. (optical pyrometer), ° C.		...	1600	1670	1620	1640		1620	1600	1665	1670		...	...	...		1630	1620	1610
Temp. of blown metal (immersion pyrometer), ° C.		1630	1650	1640	...	1680		1710	1678	1710	1698		1667	1645	1672		...	...	...
Temp. increment during blow, ° C.		360	360	330	...	380		388	360	434	435		335	350	358		...	...	...
Wt. of blown metal, lb.		5857	6580	6580	6944	6832		4592	4480	4984	4676		5635	5635	5855		5789	6013	6390
Blowing loss, % :																			
Chemical		4·8	4·8	4·2	4·1	4·3		4·5	4·9	4·8	4·7		4·8	3·6	4·8		3·7	3·5	3·8
Mechanical		7·9	3·7	8·0	8·1	8·1		4·9	7·8	3·2	4·3		4·1	2·9	2·3		4·7	1·1	1·9
Total		12·7	8·5	12·2	12·2	12·4		9·4	12·7	8·0	9·0		8·9	6·5	7·1		8·4	4·6	5·7
Casting temp. (immersion pyrometer), ° C.		1587	1600	1600	...	...		...	...	...	...		1549	1568	1575	(corrected optical readings)	1570	1550	1550

to collect on a unified basis, such information and operational data as would typify the converter practices employed. These data may be placed in two broad groups:

(i) Metallurgical; involving analyses of metal before and after blowing, slag analyses, temperatures, additions made to the metal, and blowing losses.

(ii) Operational; including details of duration of blow, blowing angle, air pressure, volume, humidity, and blowing loss.

The total loss in weight of the charge occurring during conversion (blowing loss), falls partly into both groups. The portion which is purely metallurgical is the inevitable result of the conversion, and is mentioned later in this Report under the term chemical loss. Any loss greater than that represented by the difference in composition of the charged metal and the blown metal comes under the heading of operational loss or mechanical loss.

The data obtained from a study of typical heats in the four plants is summarized in Table III. At the time this information was being collected, Plant *A* was not desulphurizing the cupola metal before conversion, though this was standard practice at the other three plants. Heats 4 and 5 from Plant *A* illustrate this use of untreated cupola metal; the remaining heats 1, 2, and 3 from the same plant were desulphurized by means of soda ash for comparison with the other data shown in the tables.

From Table III the following features characteristic of the converter practice of the individual plants are apparent, and they show the wide variations present in current practice.

Plant *A* used low carbon cupola metal of average temperature. The vessel temperature before the blow was rather low, and fairly heavy additions of ferrosilicon were made during the blow. The temperature increment obtained from conversion was of an average order, but high mechanical loss (about 8%) was experienced.

Plant *B* used high carbon cupola metal of average temperature, charged into a very hot vessel. Only very small additions of ferrosilicon were made during the blow and a high temperature increment was obtained. The mechanical loss (about 5%) may be considered moderate.

At Plant *C*, medium carbon cupola metal of average temperature was used and only small additions of ferrosilicon were made before or during the blow. The temperature increment was average and mechanical loss was low (about 3%).

The metal charged at Plants *A*, *B*, and *C* contained in the order of 1–1·2% of silicon, but Plant *D* differed from them, in that very low silicon metal with medium carbon and temperatures above the average was charged into a very hot vessel. This resulted in a relatively low temperature increment. Very small additions of ferrosilicon were made before the blow and a very low mechanical loss (about 2·5%) was obtained.

General Remarks

1. The analysis of the metal charged at Plant *D* conformed closely to the averages recorded in Table II.

2. The temperature of the vessel before the blow at Plant *A* was low, indicating a fairly long standing time between heats. Other operating conditions were similar to those recorded in Table II. The high blast pressure in heat No. 2 at Plant *D* was due to a partial blockage of the tuyeres at the commencement of the blow.

3. The additions of ferrosilicon before and during the blow, were governed by vessel temperature, metal temperature, and metal composition.

4. The highest silicon content of the blown metal was from Plant *A*, at which the largest addition of ferrosilicon was made. As it was added at various stages of the blow this indicates that the late addition of ferrosilicon leads to a less complete oxidation of the silicon owing to the presence of carbon at the prevailing high temperature. Plant *D* recorded the highest manganese content in the blown metal. Plants *A* and *B* find a reduction of sulphur due to blowing, while Plants *C* and *D* record very little difference. The phosphorus content generally, shows a small increase due to concentration of this element during the blow.

5. There were wide variations in the composition of the blowing slags, outstanding instances being the high Al_2O_3 content at Plants *C* and *D*, low FeO and high MnO contents at Plant *D*, and high CaO content at Plant *A*. The high MnO content at Plant *D* is considered to be due to the relatively small quantity of slag formed. From their composition the slags at Plants *A* and *C* would be more viscous than those at Plants *B* and *D*, and it will be noted that at these plants, the slag is not removed before adding the finishing alloys.

8. The chemical loss during blowing at all plants is determined by the composition of the metal charged and is fairly constant throughout. With the exception of Plant *C* the mechanical loss is directly proportional to the blowing time as might be expected. The exception is probably due to the converter design at that plant.

9. A note on the gas content of the metal appears relevant here. Samples taken at Plant *D*

TABLE IV—*Composition of Metal and Slag at Progressive Stages of the Blow at Plants* A *and* D

Plant *A*.							Plant *D*.						
Time, min.	Metal.			Slag.			Time, min.	Metal.			Slag.		
	C, %.	Si, %.	Mn, %.	SiO_2, %.	FeO, %.	MnO, %.		C, %.	Si, %.	Mn, %.	SiO_2, %.	FeO, %.	MnO, %.
0	2·6	1·2	0·15	...	...	...	0	3·1	0·4	0·4	...	...	...
8	2·6	1·1	0·12	39·9	53·8	2·0	2	2·9	0·2	0·2	55·4	29·9	10·1
17	2·6	0·7	0·1	39·4	54·5	2·0	4	2·6	0·05	0·05	54·2	29·4	12·2
34	2·2	0·2	0·03	...	...	...	6	2·0	0·05	0·05	54·0	39·3	12·0
44	0·9	0·04	0·02	50·9	42·9	2·5	8	1·0	0·05	0·05	56·0	28·8	10·9
49	0·04	trace	0·02	54·4	39·5	2·5	14	0·08	0·05	0·05	60·0	25·5	10·7

and analysed for oxygen and nitrogen showed the following trends :

(i) Desulphurization of cupola metal with soda-ash results in decrease in nitrogen content of approximately 50% (from 0·015 to 0·008%).

(ii) The conversion operation produces a further reduction to 0·005% of nitrogen and an oxygen content of the order of 0·06%, *i.e.*, in equilibrium with the carbon content of the blown metal.

(iii) Deoxidation and alloying result in an increase in nitrogen to 0·0075%, which is slightly higher than in open-hearth steel but lower than in electric-arc or bottom-blown bessemer steel. At the same time the oxygen content is substantially reduced to 0·004%, which compares favourably with steel made by other processes.

PART II—EXPERIMENTAL WORK

(a) *Analysis of Metal and Slag at various Stages of the Process and under varying Conditions*

As very little data was available on the changes in slag and metal composition during the blow, it was considered necessary to obtain such information from current practice, and the composition of the metal and slag at progressive stages of the blow at two Plants *A* and *D* are given in Table IV. Plant *A* may be taken as typical of the practice in which the charge to the converters is high silicon cupola metal at about 1300° C., while at Plant *D* the charge temperature is between 1400° and 1450° C., and the silicon content is low : 70 lb. of sand were put into this vessel before the metal was charged.

The samples were taken in spoons, with the blast off and the vessel tilted forward. The vessel was then put back to the original angle and the blow continued. This sampling procedure naturally resulted in an increased blowing time, especially in Plant *A* where it was accentuated by low blast volume and viscous slags.

Figures 2 and 3 show the combustion of the carbon, silicon, and manganese in the metal, and the resulting slag composition, together with some temperature readings of the metal in the bath taken at Plant *A*.

In the case of Plant *A* the carbon content remained unchanged until the temperature of the bath was 1450° C., and the silicon content was reduced to 0·7%. The rate of oxidation of the silicon increased up to this point and decreased after it. Manganese oxidized at approximately the same rate throughout the blow which took 50 min.

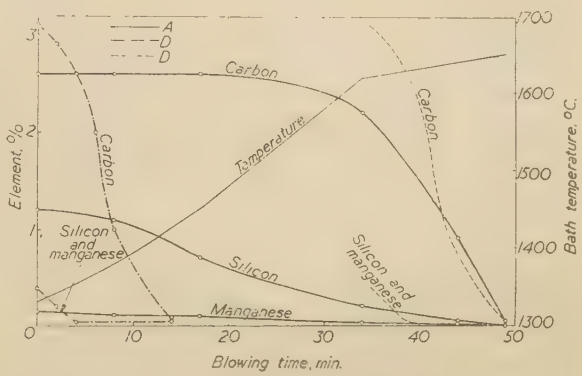

FIG. 2—Metal composition at progressive stages of the blow

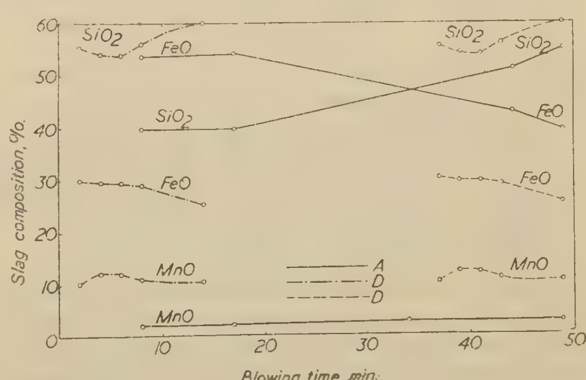

FIG. 3—Slag composition at progressive stages of the blow

In the foregoing experiment at Plant *D*, the oxidation of the carbon commenced immediately at the beginning of the blow. Manganese and silicon oxidized rapidly at first and reached end-of-blow values after 4 min. The blow was completed in 14 min.

The dotted line in Fig. 2 shows that this short blow comprises mainly the end period of the blow at Plant *A*. The temperature of the metal entering the converter at Plant *D* is of the same order as that at which the carbon commenced to oxidize at Plant *A*, although the silicon content is slightly lower, 0·4% as compared with 0·7%. The high silicon content of the bath at Plant *A* functions as a kindling agent and increases the temperature of the bath to the point at which oxidation of carbon commences. Figure 4 shows the similarity of the oxidation of carbon with diminishing silicon at the two plants. In both cases 85% of the silicon was removed before the carbon elimation proceeded with rapidity.

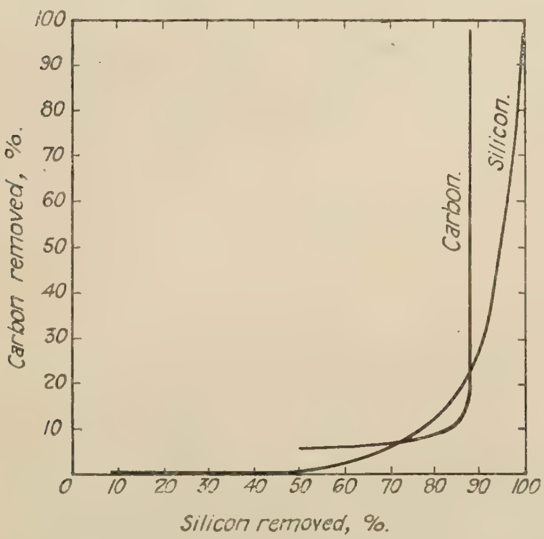

FIG. 4—Relation between oxidation of carbon and silicon in the two converter processes

The normal converter operation may be considered in three stages:

(i) A blast of air impinges on the surface of the bath of molten iron and immediately forms a layer of iron oxide (FeO). Some silicon and manganese also form their respective oxides, but the initially formed slag is mainly FeO.

(ii) From the point when the metal is given a complete cover of slag, the oxidation of silicon and manganese is accelerated and the reactions are essentially between the slag and the metal as distinct from air and metal as in the bottom-blown converter. During this period, there is a rapid rise of temperature due to the exothermic oxidation processes as detailed in Appendix I.

(iii) The second stage may be considered complete when the temperature reaches 1450° C. at which the oxidation of carbon becomes rapid. At still higher temperatures other reactions take place which result in the reduction of SiO_2 and MnO by carbon.

Oxidation of carbon in the metal by FeO or other oxides in the slag, produces CO which may burn to CO_2 in excess of air within the vessel. This represents another essential difference from the bottom-blown process, in so far as that the air passes through the metal and all of the oxygen is absorbed. The issuing gas cannot therefore be a higher oxide than CO. As a result considerably more heat is generated per unit of carbon in the side-blown process. This aspect was noted in a paper by P. C. Fassotte.* Some CO_2 may also be formed from direct combustion of carbon in the bath with air if the force of the blast removes the covering layer of slag. The resulting slag is higher in silica than in stage (i).

The orthodox operation regarding the temperature conditions and the oxidation of carbon and silicon is illustrated in Fig. 5.

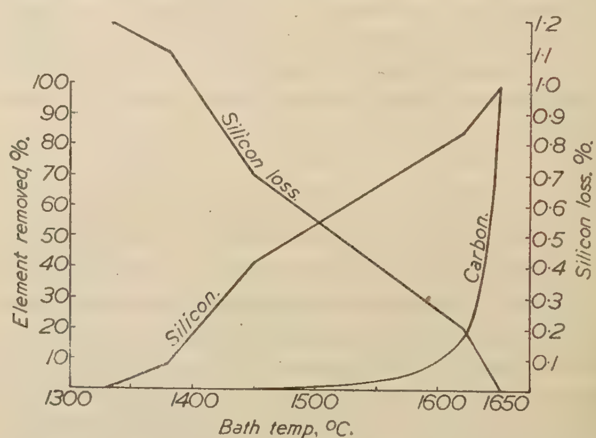

FIG. 5—Relation between bath temperature and (*a*) percentage oxidation of carbon and silicon, and (*b*) actual silicon loss

The rapid oxidation of carbon commences when the temperature of the metal is about 1450° C. with a silicon content of 0·6–0·7%, *i.e.*, about 45% of the original silicon content of the metal. At the end of the blow, the temperature will have risen to about 1650° C. It was observed that under these conditions of metal and slag, the silicon content of the metal after the addition of

* P. C. FASSOTTE, *Journal of the Iron and Steel Institute*, 1944, No. II, p. 339P.

killing agents was always higher than could be accounted for by the silicon in the alloying agents, thus indicating a reduction of some silica in the slag. This action would appear to be parallel to the acid open-hearth process in the later stages of the refining period, and may be one of the reasons for the high quality of castings made from side-blown-converter steel. The reaction varies with the temperature of the blown metal. Figure 6 shows the amount of silicon produced by the reduction of silica from the slag, plotted against the metal temperature.

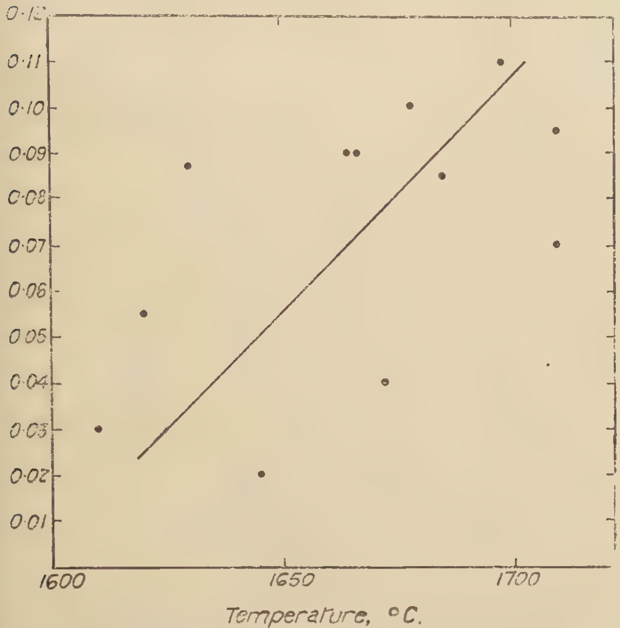

FIG. 6—Effect of temperature on reduction of silica from the slag

In the operation at Plant *D* the initial temperature of the metal is in the range at which stage (ii) of the orthodox converter operation starts, *i.e.*, 1400–1450° C. As a result, rapid oxidation of the carbon commences at the beginning of blowing. Therefore it would appear that given sufficient carbon in the bath and a temperature of this order, metal of very low silicon content may be blown successfully. Practical considerations for the production of castable steel for thin-walled castings of the composition mentioned previously place the limits at 1400° C. and 0·3% of silicon.

In the case of metal of higher silicon content as used at Plant *A*, the oxidation of approximately 0·4% of silicon heats the bath to the critical temperature. There is a critical silicon content below which, in an orthodox operation, a blow would not be castable. This content is of the order of 1·0% with a normal temperature of 1300° C. and carbon content of 3%.

(b) *The Temperature Increment Obtainable from Metal under various Conditions*

The temperature increment in the heats investigated showed a wide variation between 250° and 435° C. The lowest figures were obtained at Plant *D*, which were to be expected as the metal is superheated before charging into the converter. The average obtained at the other plants was of

TABLE V—*Analysis of Metal Blown and Heat Increment*

Plant.	Metal.			Temperature, ° C.			Carbon Equivalent, %	Ratio Temp. Increment / Carbon Equiv.
	C, %.	Si, %.	Mn, %.	Start.	Finish.	Increment.		
A	2·7	2·1	0·2	1290	1650	360	4·55	80
	2·8	1·9	0·3	1270	1630	360	4·50	80
	2·5	1·6	0·3	1320	1660	340	3·94	86
B	3·3	1·3	0·5	1318	1678	360	4·52	80
	3·4	0·7	0·3	1295	1685	390	4·06	96
	3·2	1·3	0·3	1295	1698	435	4·38	99
C	3·2	1·3	0·4	1332	1667	335	4·4	76
	2·4	1·0	0·4	1294	1645	350	4·04	86
	3·0	1·5	0·4	1314	1672	358	4·42	81
D	3·1	0·3	0·3	1430	1696	266	3·42	78
	3·1	0·4	0·3	1435	1685	250	3·50	72
	3·0	0·4	0·3	1390	1660	270	3·40	80

the order of 360° C. Details are given in Table V of three typical heats from each plant.

The carbon equivalent (C.E.) for the heat charged to the converter is that amount of carbon which is thermally equivalent to the total content of carbon, silicon, and manganese. The heat of oxidation of these elements to CO_2, SiO_2, and MnO respectively, was taken as 8100, 7000, and 1653 kg. cal./kg. The carbon equivalent was then calculated from the sum of these, divided by 8100.

It is apparent from the first examination of the results obtained in the above heats, that there is a relationship between the carbon equivalent and the increment of temperature (Fig. 7). There is an indication that the lower limit of the temperature at which a low silicon iron may be successfully blown is governed somewhat by the carbon content of the iron. The temperature increment varies inversely with the initial temperature of the bath, as shown in Fig. 8. The two curves are superimposed in Fig. 9 and this may be used to decide the ferrosilicon additions to a charge of known temperature and approximate composition.

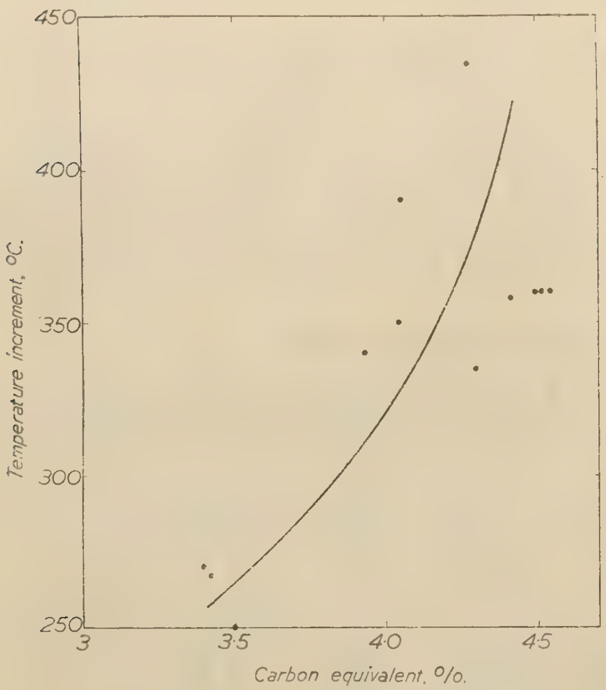

FIG. 7—Carbon equivalent and temperature increment

With a high initial bath temperature, say 1400° C., the necessary increment of temperature being low (from the graph about 270° C.), the carbon equivalent required is only 3·58%. If we subtract the carbon content of the charge, the silicon content required can be easily calculated. A low initial temperature (about 1300° C.) requires an increment of 370° C. and a carbon equivalent of 4·3%.

Further tests were carried out at Plant *A* on the temperature increment from metal of constant carbon and manganese with varying silicon content. The results are shown in Table VI.

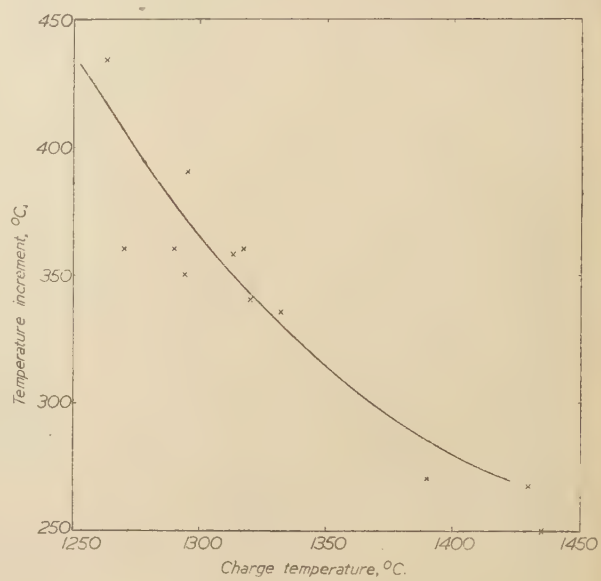

FIG. 8—Charging temperature and temperature increment

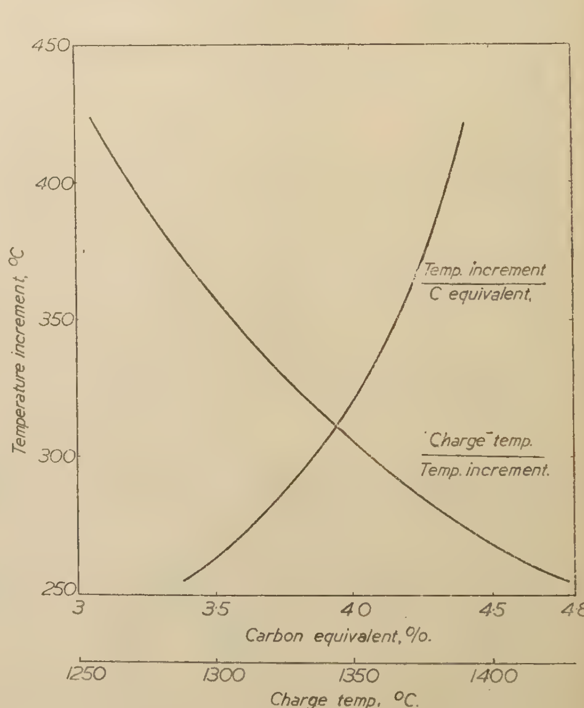

FIG. 9—Silicon addition required for a given temperature increment

The data is illustrated graphically in Fig. 10 as the relation between the ratio of the blowing time to the total silicon content and the temperature increment. The relation is shown for two ranges of carbon content, 2·7–2·8% and 3·0–3·1%. The same increment of temperature can be obtained for the upper range of carbon content with low silicon as can be obtained for the lower range with high silicon if the blowing time is the same in each case. When the blowing time is increased, as the result of say, low blower output, the losses of heat due to radiation and other forms of heat transfer are increased, with a resulting lower temperature increment. In most cases the carbon content is in the higher range, and the necessary temperature increment could have been obtained with a lower silicon content.

TABLE VI—*Heat Increment from Metal of Varying Silicon Content*

Carbon Range, %.	Silicon Content, %.			Duration of Blow, min.	Temperature, ° C.			C.E., %.	Ratio Temp. Increment / Carbon Equivalent
	Original.	Added.	Total.		Start.	Finish.	Increment.		
2·7 to 2·8	0·6	1·5	2·1	29	1290	1670	380	4·56	83
	0·7	1·1	1·8	28	1270	1660	390	4·30	90
	1·1	0·3	1·4	26	1350	1710	360	3·95	91
	0.8	0·3	1·1	26	1320	1650	330	3·70	81
3·0 to 3·1	1·2	0·5	1·7	28	1270	1680	410	4·51	91
	0·5	0·9	1·4	18	1270	1680	410	4·25	96
	0·9	0·4	1·3	30	1320	1690	370	4·17	90
	0·3	0·9	1·2	19	1290	1650	360	4·08	88
	0·6	0·5	1·1	21	1290	1690	400	4·00	100
2·3 to 2·5	0·8	0·8	1·6	27	1310	1670	360	3·78	95
	0·8	0·8	1·6	30	1320	1690	370	3·78	98

(c) *Analysis of Exit Gas from the Converter*

The objects of taking samples of gas were to study the nature of the combustion of the carbon, and to obtain data for heat and material balances of the process. For these purposes spot and average samples respectively were required.

A considerable amount of work was done before a sampling procedure was agreed upon and the investigators are still not satisfied that truly representative samples are obtained, but it is thought desirable to record the difficulties encountered. These difficulties and the method finally adopted are described in Appendix II.

Typical examples of gas analyses are given in Tables VII and VIII.

Given representative samples, it should be possible to relate the analysis results of the spot samples to the metal composition at varying stages of the blow, with carbon dioxide low during the period of oxidation of silicon and manganese, and increasing during the oxidation of carbon. The analyses of further samples are recorded in Table IX, which shows the full history of a blow at Plant *C*.

These gas analyses and the calculated excess air would suggest that the blast should have been reduced towards the end of the blow. However,

TABLE VII—*Spot Samples Taken During Individual Heats*

Plant.	Time Sampled after Commencement, min.	Composition of Gas, %.			
		CO_2	O_2	CO	N_2
A	6	6·6	nil	nil	93·4
	10	5·9	0·6	nil	93·5
	14	10·4	nil	3·2	86·4
	20	10·1	nil	10·3	79·6
C	4	1·5	14·4	nil	83·1
	13	12·4	1·7	nil	85·9
	21	11·7	1·2	nil	87·1
D	1	6·4	0·3	0·9	92·4
	4	12·0	0·1	0·7	87·2
	8	12·8	nil	0·2	87·0
	11	12·4	0·6	0·1	86·9

TABLE VIII—*Average Samples from Different Heats*

Plant.	Heat No.	Composition of Gas, %.			
		CO_2	O_2	CO	N_2
	19/10	10·6	3·3	3·4	82·7
	50/10	11·8	4·2	1·3	82·7
C	4	11·1	1·2	nil	87·7
	6	9·9	5·1	nil	85·0
	5427	11·8	1·8	nil	86·4
	8376	12·6	0·4	1·2	85·8
D	9703	12·1	3·5	0·3	84·0
	3159	12·6	3·3	0·5	83·7

further work described later showed that the method of sampling was unsatisfactory and that the samples taken were not representative of the conditions inside the vessel.

If the gas samples obtained were truly representative, it should be possible to calculate the blowing loss from the analysis, but it was found that a calculated loss did not agree with the weighed loss. Had more oxygen or carbon dioxide been present in the average sample the calculated and weighed losses would have agreed. The inference was that some oxygen was being lost above tuyere level by the oxidation of FeO fume and/or carbon monoxide, or that some carbon dioxide was being reduced by iron vapour. If the latter were the case, precipitation of carbon would be expected.

In order to explore these points, it was decided to take simultaneous samples at points 2 ft. and 4 ft. above the tuyeres and the results are set out in Table X.

The bottom sampling hole became blocked with slag after 1 min. blowing and both samples were therefore cut off at this stage in order to make them comparable. It will be seen that the upper sample was very similar to the spot sample at 1 min. reported in Table VII, and its lower oxygen content, compared with that at 2 ft. above the tuyeres, confirmed the inference of further consumption of oxygen above the lower point.

Samples were also taken at three circumferential points in a horizontal line 4 ft. above the tuyeres at Plant *B*, in order to check the possibility of variations at a given level inside the vessel. During the blow of one heat before taking the samples, it was observed that there was a strong constant flow of gas from the hole immediately above the tuyeres, a slightly weaker but constant flow from the hole to the right, and a weak intermittent flow from the left hole after

TABLE IX—*Variation in Exit Gas Composition During a Blow*

Time from Commencement, min.	Remarks and Appearance of Flame.	Blast Volume, cu. ft./min.	Composition of Gas, %.				Excess Air, %.
			CO_2	CO	O_2	N_2	
0	Blast on	1930	...	...	...	...	...
2	Little slag ejection. Large amount of fume. Small flame	1620	8·2	0·0	12·0	79·8	60·0
3	Boil commenced. Larger white flame ...	1620	...	...	...	...	...
5	Fairly vigorous boil. Large white flame ...	1620	14·8	0·0	6·8	78·4	34·0
6	Vigorous boil. Large white flame	1620	14·2	0·0	2·0	83·8	10·0
7	Addition of 12 lb. of ferrosilicon	1620	...	...	...	...	...
8	Much smaller flame	1930	...	...	...	...	...
11	Addition of 12 lb. of ferrosilicon	1930	...	...	...	...	...
12	Increase in flame	2450	14·0	0·0	4·6	81·4	23·0
17	Slightly smaller but hotter flame	1620	11·4	0·0	5·4	83·2	27·0
17·5	Long lilac flame	1930	...	...	...	...	...
19	Long lilac flame	1930	7·2	0·0	11·0	81·8	55·0
20	Slightly less flame	2450	2·8	0·0	16·6	80·6	83·0
20·5	Drop of flame	...	...	...	...	...	...

TABLE X—*Variation in Gas Composition in Different Vertical Zones in the Converter, at Plant* D

Distance above Tuyeres, ft.	Composition, %.			
	CO_2	O_2	CO	N_2
2	5·0	6·2	nil	88·8
4	5·5	1·8	nil	92·7

2 min. blowing. These comparative rates of flow persisted during the next heat when the samples were being taken. The results are given in Table XI.

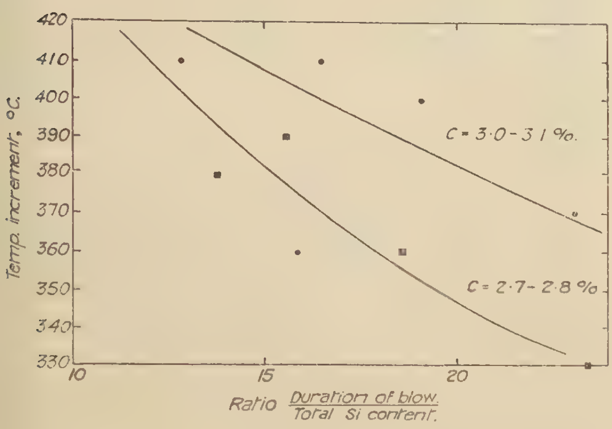

FIG. 10—Variation in temperature increment with silicon content and blowing time

The analyses show that various degrees of combustion exist simultaneously in different positions at the same horizontal level within the vessel. As the observations and tests were made on a newly veneered vessel, uneven shape due to wear was unlikely to be a contributory cause to these variations.

Temperature of the Gas

A thermocouple was built into the sampling pipe which was arranged for the test reported in Tables VII and VIII in order to obtain the temperature of the gas as it left the converter. The result is shown in the graph in Fig. 11.

TABLE XI—*Variation in Gas Composition at Different Points in a Horizontal Line 4 ft. above the Tuyeres at Plant* B.

Positon of Sampling Hole.	Composition of Gas, %.			
	CO_2	O_2	CO	N_2
Centre-line of tuyeres ...	5·0	4·2	2·5	88·3
75° to left ...	5·3	5·0	0·6	89·1
75° to right ...	5·5	3·5	0·9	90·1

There was a straight-line increase up to a point corresponding to a temperature of 600° C. in the first 5 min. of the blow, followed by a rapid steepening of the curve with a further corresponding temperature increase of only 45° C. during the remainder of the blow.

Solids Carried by the Gases

Observations made at Plant *B* during a blow, before taking a series of gas samples, showed that when the combustion of carbon became rapid as evidenced by the rise of the "carbon" flame, a bluish smoke appeared around the small flames issuing from the gas sampling holes which were not at this stage closed by the insertion of the sampling tubes. On the examination of the interior of the tubes after taking the gas samples, dust-like deposits were found in each. During the sampling, the gas issuing from one of the bleeders impinged directly against a steel stanchion standing a short distance away, forming a deposit.

At Plant *D*, an examination of tubes used for gas sampling showed a similar deposit, and this was analysed along with those from Plant *B*, with the results shown in Table XII.

TABLE XII—*Analysis of Deposit from Various Sources at Plants* B *and* D

Plant.	Source.	Composition of Deposit, %.						
		Carbon.	Silica.	Metallic Iron.	Ferrous Oxide.	Ferric Oxide.	Manganous Oxide.	Total.
B	Main pipe	0·24	13·67	76·8	...	...	0·73	91·44
	Bleeder (1)	0·5	1·4	78·3	...	...	0·58	80·78
	Bleeder (2)	1·2	2·4	78·8	...	...	0·57	82·97
	Stanchion	0·5	1·6	77·7	...	...	0·80	80·60
D	Main pipe	5·8	4·0	...	32·4	57·4	0·4	100·0

Evidence of the existence of free metallic iron in the deposits was found in the Plant *B* samples and the figures shown indicate that with the iron assumed to be ferrous oxide only, the total would

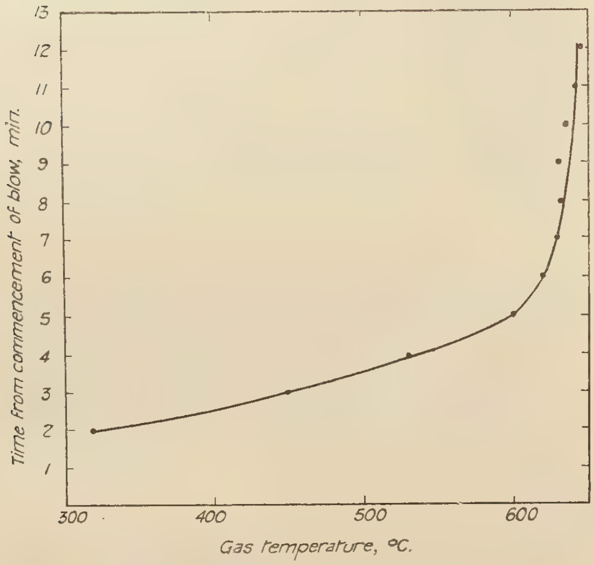

FIG. 11—Temperature variation of exit gas during the blow

exceed 100%. At Plant *D*, both ferrous and ferric oxides were found and the carbon content of the deposit was much higher than in the Plant *B* deposits. The presence of free carbon in the gas may be taken as confirming equations 10 to 14 of Appendix I, and it may also partly explain the luminosity of the flame. In addition, it indicates endothermic conditions confirmed by the comparatively low temperature of the gas.

Observations on Results

The conclusions to be drawn from the large amount of work carried out on the sampling and analysis of the exit gases are as follows :

(i) The main reaction at tuyere level produces carbon monoxide, some of which is burnt to carbon dioxide higher up in the vessel.

(ii) There is evidence of the presence of free carbon in the gas. This may explain the luminosity of the flame and also indicates the occurrence of endothermic reactions within the vessel.

(iii) The method of sampling outlined is unsatisfactory and does not permit the obtaining of a truly representative sample. Further work is clearly necessary, and this could be more readily carried out if an experimental vessel were available.

(iv) It is customary to vary the blast volume during the blow and the need for this, according to the requirements for oxidation of the silicon, manganese, and carbon, is indicated by the results presented. Such control prevents chilling of the vessel and bath by excess air in the early stages of the blow.

(v) A measure of the efficiency of the plant becomes possible if reliable gas sampling can be carried out.

(d) *Investigation of Chemical and Mechanical Conversion Loss*

The overall conversion losses in the side-blown converter result from two causes : (*a*) chemical, and (*b*) mechanical. Chemical loss is due to the inevitable loss of iron, silicon, manganese, and carbon, the iron loss amounts depending on slag composition and weight. Mechanical loss is due to metal, slag, and fume being ejected from the converter, particularly during the period of violent action of the bath.

Chemical loss may be decreased by charging metal of low carbon and silicon content at a high temperature. Mechanical loss needs further investigation as it can be minimized, and in any case should be kept as low as possible for economic reasons. It was therefore studied from figures obtained as follows :

The chemical-loss weight was calculated from the analyses of the fifteen experimental heats recorded in Table III, and the mechanical loss was estimated by subtracting the calculated loss from the total weighed loss.

Fig. 12 shows that there is a trend towards a

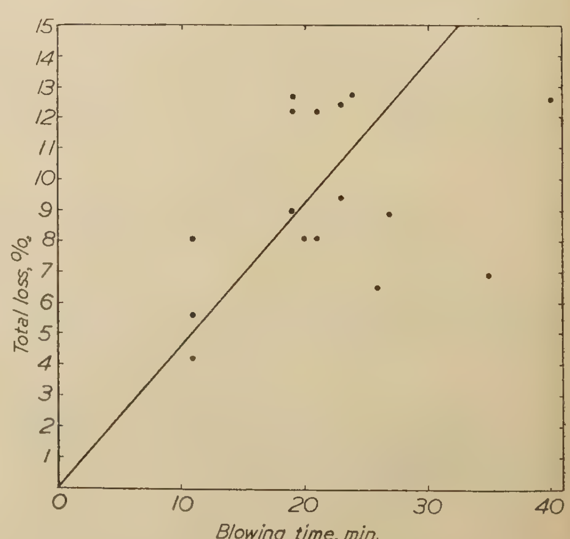

FIG. 12—Relation of total conversion loss with blowing time

irect relationship between total loss and blowing ime. The length of the blow is determined to ome extent by the content of oxidizable elements, nd the chemical loss in a long blow is therefore reater than in a short one. The mechanical loss aries with the length of the blow, as ejections ake place over a longer period, and furthermore, ilica is eroded from the vessel lining and thus nore FeO is needed to approach equilibrium onditions.

The relationships between mechanical loss and lowing time, silicon content, and initial temperaures are plotted in Figs. 13, 14, and 15. The eneral curve in Fig. 13 indicates that there is a lower decrease in this loss as blowing time ncreases.

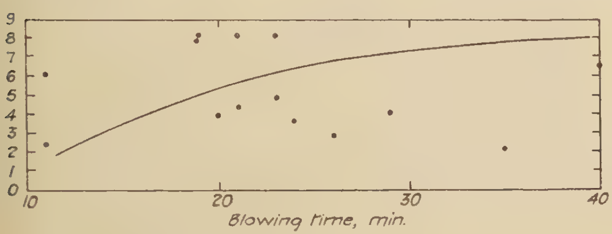

FIG. 13—Effect of blowing time on mechanical loss

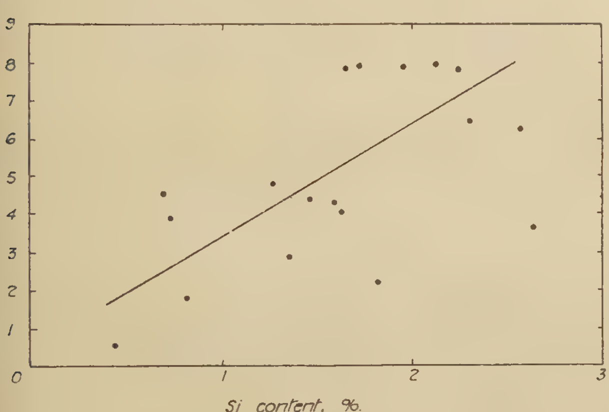

FIG. 14—Effect of silicon content on mechanical loss

There appears, however, to be a direct relationship between mechanical loss and silicon content of the metal charged, especially if additions are made during the blow. In such cases the effect is to reduce temporarily the number and size of the ejections, but this is invariably followed by a most pronounced boil.

A consideration of the effect of silicon leads to the examination of the effect of the temperature of the metal charged. The general trend seen in Fig. 15, is for a lower mechanical loss from the use of higher temperature metal. This is more likely to be the case if the silicon content and/or additions are regulated by the metal temperature.

(e) *Investigation of Tuyere Arrangement and Air Supply.*

A few experiments were made at Plant *C* in an attempt to find the factors relating the distribution of the air in the vessel to the blowing time and temperature increment. Previous experience had shown that the tuyere diameter exercised a considerable effect on the blowing time. With $1\frac{3}{8}$-in. dia. tuyeres the blowing time was 30 min., but with 1-in. dia. this increased to 50 min. The investigation was continued in order to determine more clearly the relationship, if any, between the blowing time and the tuyere diameter.

Sets of seven tuyeres of $1\frac{5}{8}$-in. and $1\frac{3}{4}$-in. dia., six of 2-in., and five of $2\frac{1}{2}$-in. dia. were tried, and it was found that the blowing time was affected. The physical effect on the air supply to the bath of an increase in tuyere area is a reduction in the speed and pressure of the air at the surface of the bath, *i.e.*, a reduction in the "jet effect." This lack of penetrative power of the blast might explain the increased blowing time required with

TABLE XIII—*Effect of Tuyere Variation on Blowing Time*

Vessel capacity, 50 cwt. Blast volume, 1900 cu. ft./min.

Tuyere dia., in....	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$
No. of tuyeres ...	7	7	7	6	5
Total area, sq. in.	10·4	14·5	16·8	18·8	24·5
Approx. blowing time, min. ...	30	30	25	20	30

the $2\frac{1}{2}$-in. dia. tuyeres. These experiments show that a considerable increase in efficiency may be obtained from the use of a correct number and size of tuyeres, and that the optimum conditions would repay investigation at all plants.

PART III—HEAT BALANCE OF THE SIDE-BLOWN CONVERTER PROCESS

Table XIV gives a summary heat balance calculated for two typical heats from each of the four plants and also gives the relevant heat data used in the calculations. The absence of reliable gas samples renders the heat loss in waste gas incalculable and this has to be included with radiation loss.

Considering only the percentage column in order to eliminate the variations in heat quantities due to differences in charge weight, certain trends are readily seen.

On the input side, high-temperature iron (Plant *D*) is associated with the highest sensible heat, and the lower temperature iron of low carbon and silicon content (Plant *A*) with the lowest sensible heat. In descending order of magnitude of sensible heat of the iron, the plants may be arranged thus : *D*, *B*, *C*, and *A*.

The heat produced during the blow by the oxidation of carbon, silicon, manganese, and iron increases with the proportion of these elements oxidized. Plant *A*, where ferrosilicon was added to raise the silicon content of the low carbon low silicon iron, showed the highest heat of oxidation (62·3%), with Plant *D* the lowest (48·2%). The order is exactly reversed, becoming *A*, *C*, *B*, and *D* in descending order of heat of oxidation.

A similar reversal of trend is found on the output side of the heat balance sheet, the sensible heat of the blown metal decreasing in the order *D*, *B*, *C*, and *A*, whilst the total heat lost in the waste gases and by radiation decreases in the order *A*, *C*, *B*, and *D*.

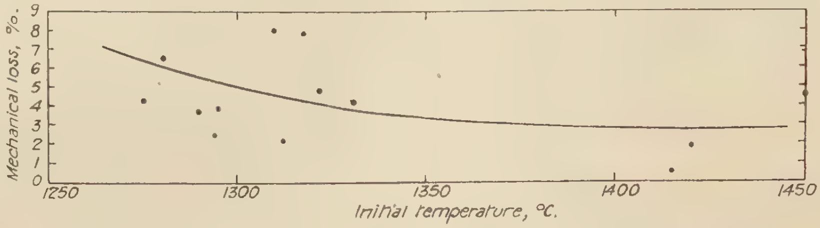

FIG. 15—Influence of initial temperature on mechanical loss

TABLE XIV—*Summary Heat Balance of Side-Blown Converter Process*

Heat No.	Plant *A*.				Plant *B*.				Plant *C*.				Plant *D*.			
	1		3		1		6		4		6		1		3	
	Heat Content		Heat Content		Heat Content		Heat Content		Heat Content		Heat Content		Heat Content		Heat Content	
	kg. cal.	%.	kg. cal.	%.	kg. cal.	%.	kg. cal.	%.	kg. cal.	%.	kg. cal.	%.	kg. cal.	%.	kg. cal.	%.
Heat Input.																
Sensible heat of iron	821,180	37·5	945,550	39·8	654,000	45·2	637,000	44·2	797,940	42·7	805,140	42·9	855,000	52·1	896,100	49·9
Oxidation of C, Si, Mn, & Fe ...	1,364,840	62·3	1,422,660	60·0	782,170	54·1	788,610	54·7	1,065,380	57·0	1,066,740	56·8	771,600	47·0	884,400	49·3
Slag formation ...	3,270	0·2	4,700	0·2	9,480	0·7	16,300	1·1	5,400	0·3	6,440	0·3	14,400	0·9	13,700	0·8
Total... ...	2,189,290		2,372,910		1,445,650		1,441,900		1,868,720		1,878,320		1,641,000		1,794,200	,,
Heat Absorbed.																
Sensible heat of blown metal ...	940,430	42·9	1,052,000	44·3	754,000	52·2	764,000	53·0	950,300	50·9	936,320	49·8	915,200	55·8	1,013,000	56·6
Slag	21,990	1·2	33,210	1·4	56,700	3·9	98,900	6·9	44,000	2·3	60,500	3·2	82,500	5·0	82,500	4·3
Heat in ejections	...		...		38,060	2·6	9,480	0·6	53,350	2·9	51,300	2·8	...		...	
Heat in waste gases, radiation loss, &c. ...	1,223,870	55·9	1,287,700	54·3	596,890	41·3	569,530	39·5	821,070	43·9	830,200	44·2	643,300	39·2	698,700	38·9
Total... ...	2,189,290		2,372,910		1,445,650		1,441,900		1,868,720		1,878,320		1,641,000		1,794,200	

DATA used in the Calculations.

$C \rightarrow CO_2$ = 8100 kg. cal. per kg. of carbon.
$C \rightarrow CO$ = 2430 ,, ,, ,, ,, ,, ,,
$Si \rightarrow SiO_2$ = 7000 ,, ,, ,, ,, ,, silicon.
$Mn \rightarrow MnO$ = 1653 ,, ,, ,, ,, ,, manganese.
$Fe \rightarrow FeO$ = 1173 ,, ,, ,, ,, ,, iron.

$2FeO + SiO_2 \rightarrow 2FeO.SiO_2$ = 148 kg. cal. per kg. of SiO_2.
Heat content of slag = 550 kg. cal. per kg. ± 0·25 kg. cal. per 1° C. difference from 1650°C
,, ,, ,, steel = 350 ,, ,, ,, ,, ± 0·20 ,, ,, ,, ,, ,, ,, ,,
Latent heat of fusion of slag = 95–100 kg. cal. per kg.
,, ,, ,, ,, ,, iron = 66–69 ,, ,, ,, ,,

The thermal efficiency may be estimated by consideration of the sensible heat of the iron, the sensible heat of the blown metal, and the heat of oxidation of carbon, silicon, manganese, and iron, the latter being equivalent to the fuel consumption.

$$\text{Overall thermal efficiency} = \frac{100\ (\text{heat in blown metal—heat in iron})}{\text{Heat of oxidation}}.$$

The values obtained for the process as operated at the four plants studied, are shown below :

Plant A.	*Plant* B.	*Plant* C.	*Plant* D.
8·2%	14·5%	13·3%	10·8%

It will be observed that the figures at Plants *B* and *C* compare fairly closely with some figures which have been given for the open-hearth furnace (17%). The lower values at Plants *A* and *D* are to be attributed to the more extreme operating conditions typical of those plants as indicated in the general summary given previously in the Report.

It is hoped that future work will enable reliable verage gas samples to be obtained. With this nformation, the heat loss in the waste gases can e calculated and separated from that lost by adiation, and a more detailed heat balance may hen be calculated.

'ART IV—CONCLUSIONS AND RECOMMENDATIONS

The investigations have shown that there is a vide variation in converter design and operation nd in the composition and temperature of the netal charged at the four plants studied. There s reason to believe that even wider differences xist amongst the many firms operating side-lown converters. It is interesting to note, howver, that despite these differences the quality of he finished steel is uniformly high, having roperties similar to open-hearth steel. This is ot surprising as the study has shown the side-lown converter process to be predominantly one f metal–slag reaction and not one of metal–air eaction as in the Bessemer process. Another imilarity to the open-hearth process is that silica n the slag is reduced during the last stages of he blow, this reaction being accelerated in the ase of high-temperature heats.

The silicon in the metal charged into the converter functions as a kindling agent, as its oxidaion raises the temperature of the bath to a point t which the rapid oxidation of carbon commences, .e., 1450° C. It follows that the initial temperaure of the metal has a large bearing on the amount f silicon necessary to raise the temperature of he bath to this critical point. Additions of ferroilicon are often made before or during the blow nd it is suggested that economies in working vould result from the correlation of these additions with the temperature and composition of the netal charged. In any case, ferrosilicon additions o very hot iron should be limited if the risk of xcessive silicon in the blown metal is to be voided. A high carbon content in the metal harged is desirable and this can be obtained by using cupolas having deep wells.

Good side-blown converter practice shows an overall thermal efficiency only slightly lower than hat of the usually accepted order in the acid open-hearth process (14–17%). Lower thermal efficiencies result from more extreme operating conditions, *e.g.*, low vessel temperature at charging, low carbon metal, large ferrosilicon additions during the blow, and low silicon metal of high temperature.

The conversion loss with the current practice at the plants examined varies from 6 to 13%, and the Report indicates that attention to details of operation should result in a uniformly lower loss than the present average.

Metal composition, blast volume, tuyere area, bath area, and depth of well, are all related as regards economical working of the process but further experimental work is necessary before the ideal design of plant can be suggested. There are indications that desirable conditions include a shallow well and a fairly large distance from tuyeres to nose.

The Sub-Committee retains an open mind on the value of converter gas composition and its relationship to the metallurgical changes taking place. They consider, however, that provided representative samples of the gaseous products of reaction can be obtained, it is likely that important information regarding the reactions in the converter and its efficient working could be deduced from the gas analyses. One very interesting feature of the investigation was the revealing of the presence of free carbon in the gas, indicating the reduction of carbon dioxide and/or carbon monoxide and consequent endothermic conditions.

It appears advisable to vary the blast volume during the blow to allow for the varying requirements of air for oxidation and in order to reduce to a minimum any chilling effect on the bath and heat lost in ejections.

Experiments have of necessity taken second place to production demands and are likely to do so in the future. It is suggested that the best method of obtaining reliable and comparative information regarding variables in design and operation is by continuing the investigations in an experimental plant.

APPENDIX I—*Reactions and Heat Values of the Side-Blown Converter Process**

1.	$2Fe + O_2 \rightarrow 2FeO$	+129,000 g. cals.	
2.	$2Mn + O_2 \rightarrow 2MnO$	+193,000 ,,	
3.	$Si + O_2 \rightarrow SiO_2$	+208,300 ,,	
4.	$2C + O_2 \rightarrow 2CO$	+ 53,140 ,,	
5.	$2CO + O_2 \rightarrow 2CO_2$	+135,000 ,,	
6.	$C + O_2 \rightarrow CO_2$	+ 94,220 ,,	
7.	$Mn + FeO \rightarrow MnO + Fe$	+ 32,000 g. cal.	
8.	$Si + 2FeO \rightarrow SiO_2 + 2Fe$	+ 79,000 ,,	
9.	$Si + 2MnO \rightarrow SiO_2 + 2Mn$	+ 15,300 ,,	
10.	$Si + 2CO \rightarrow SiO_2 + 2C$	+155,160 ,,	
11.	$Si + CO_2 \rightarrow SiO_2 + C$	+114,080 ,,	
12.	$2CO \rightarrow CO_2 + C$	− 41,080 ,,	
13.	$Mn + CO \rightarrow MnO + C$	+ 69,930 ,,	
14.	$2Mn + CO_2 \rightarrow 2MnO + C$	+ 98,780 ,,	
15.	$Mn + CO_2 \rightarrow MnO + CO$	+ 28,850 ,,	
16.	$C + FeO \rightarrow CO + Fe$	− 37,930 ,,	
17.	$C + MnO \rightarrow CO + Mn$	− 69,930 ,,	
18.	$2C + SiO_2 \rightarrow 2CO + Si$	−155,160 ,,	
19.	$2Fe + SiO_2 \rightarrow 2FeO + Si$	− 79,300 ,,	
20.	$2Mn + SiO_2 \rightarrow 2MnO + Si$	− 15,300 ,,	
21.	$2CO + O2 \rightarrow 2CO_2$	+135,300 g. cals.	
22.	$FeO + SiO_2 \rightarrow FeSiO_3$	+ 5900 ,,	Slag-forming reactions.
23.	$2FeO + SiO_2 \rightarrow Fe_2SiO_4$	+ 11,300 ,,	
24.	$MnO + SiO_2 \rightarrow MnSiO_3$	+ 1500 ,,	

* The heat values are by H. Ulick, C. Schwartz, and K. Cruse, from *Archiv für das Eisenhüttenwesen*, May 1936–7, vol. 10, p. 493.

D

APPENDIX II—*Method of Taking Samples of the Exit Gas from a Converter*

The first method was to place a mild-steel tube bent at right angles, 12 in. inside the nose of the converter, collecting the sample in a glass sampling tube filled with gas-saturated water. This method had the disadvantage of the end of the tube becoming white hot and melting off before the sample was collected. A modification comprised making a hole through the lining near the top of the vertical part of the vessel from which the sample was collected. The sampling pipe did not become overheated, but it was then realized that owing to its length (7–11 ft.) the 200 c.c. sample obtained was only in the nature of a spot sample of the gas in the pipe at the time of connecting to the sample tube. It was also considered possible that if the sampling pipe temperature reached that of red heat, some reaction of CO_2 and O_2 with the metal would vitiate the results obtained. The method finally adopted was as follows :

A hole was made in the shell of the converter on the tuyere side, 1 ft. below the joint of the nose and body, and a $1\frac{3}{4}$-in. tuyere block was built into the lining to coincide with the hole. The sampling pipe comprised a bleeder near the end, which enabled the gas to be representative of the composition in the vessel at all stages of the blow, (Fig. 16). The sampling pipe was placed in the hole before the blast was put on, and any space around the pipe was filled with plastic refractory to prevent the passage of hot gases and flame from heating the tube. Precautions taken against the reaction of carbon dioxide and/or oxygen with the tube should it become hot were, to line the side tube with a laboratory-type silica combustion tube, and to coat the inside of the down tube with a refractory wash for 1 ft. of its length.

The sampling bottle was of 5 l. capacity fitted with a two-hole rubber bung bearing a gas-inlet tube and a syphon outlet. The bottle was filled with water either acidulated with sulphuric acid or previously saturated with converter gas, and the two tubes in the bung were fitted with rubber connecting pipes with screw clips. The gas-inlet tube and connecting tube were as short as possible in order to minimize the " dead end " of the column of gas being drawn into the bottle. The end of the syphon outlet was drawn out to form a jet to allow the sampling bottle to be emptied in a little longer time than the normal duration of a blow.

In taking a sample, gas was allowed to flow through the tube for a short time in order to clear it of air before connecting to the bottle. After having made the connection the syphon was started, the action being one of the continuous drawing away of a small amount of gas which was being constantly changed in the tube by passing on through the side bleeder. When spot samples were required the bleeder was stopped up and the gas was collected in the bottle. On opening the bleeder again, the tube was rapidly scavenged and refilled with gas of a different composition for the next spot sample.

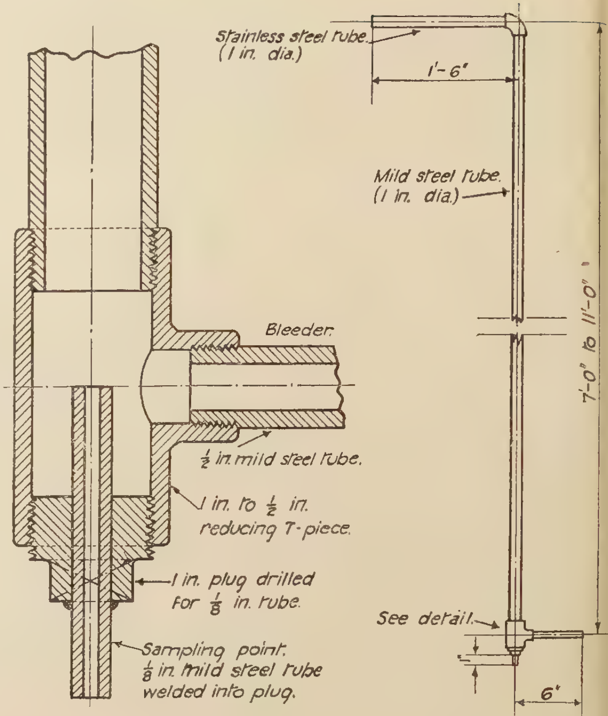

FIG. 16—Pipe for obtaining samples of exit gas

At the end of the blow, both tubes from the bottle were quickly shut off by means of the screw clips. Analysis of the gas was carried out in an Orsat type of apparatus, water being introduced into the sampling bottle through the syphon as the gas was drawn out.

ACKNOWLEDGMENTS

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Fluctuations of the Distribution of Torque Between Rolling-Mill Spindles*

By E. A. W. Hoff, Ph.D.†

SYNOPSIS

The paper describes fluctuations of torque found when the torques acting in the two connecting spindles of a two-high rolling mill were recorded separately and independently during the operation of the mill. Some of these fluctuations were periodical and in step with the roll revolutions. These are attributed to mechanical imperfections of the driving gear. Other non-periodic fluctuations are thought to be caused by the surface condition of the rolled stock. In an Appendix it is shown that none of the fluctuations found could have originated from the universal joints of the spindles.

CERTAIN phenomena well known to rolling-mill operators, like variations of the surface finish along the strip, or the curving of the rolled stock around one roll, suggest that the torque acting on one roll during the pass can be unsteady and different from the torque acting on the other roll. As our torque-measuring equipment allows us to record fast variations of the torque on each working roll separately, it seemed worth while to make a short investigation of this point.

Method

The torquemeters consist of electric-resistance strain gauges attached to both connecting spindles between pinion-box and rolls. The strain gauges are connected to form two Wheatstone bridge circuits, one for each spindle. A torque acting on a spindle produces a proportional deflection of the corresponding bridge galvanometer. These deflections are recorded photographically on a strip of bromide paper moving at constant speed. The Figs. 1–11 show reproductions of such photographic records,

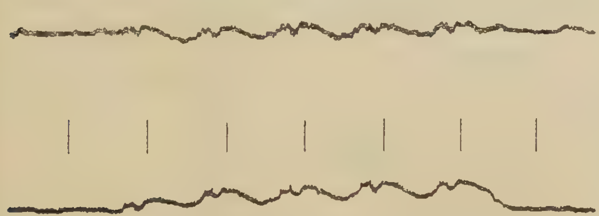

FIG. 1—Rolls pressed together with a load of 4·4 tons on each bearing. Rolls cleaned with benzene, ether, and rubbed dry with clean cotton-wool (rolls dry)

reduced in size, in which the time axis runs from left to right. In Figs. 1–7 and 9–11 the scale of the vertical axis is 80 kg.cm./mm. (58 lbs. ft./mm.), both for upper and lower rolls. The roll-neck bearing friction contributes 0·5–1·5 mm. to the deflection. On some of the records there are time marks whose spacing corresponds to one revolution of the rolls (diameter 160 mm.). The torque on the lower roll is recorded as a deflection upwards from a zero-line at the bottom, while the torque on the upper roll has its zero-line on top with deflections downward. Except in Figs. 1 and 2, these deflections cross over.

Torque Records

A conspicuous feature of the records is that the two deflections give traces which nearly coincide if one is superimposed on the other. As the deflections are in opposite directions, this means that the total torque transmitted to the rolls remains approximately constant. This agrees with previous experiments where only the total torque had been recorded and found to give practically a straight line, as in Fig. 8, which has been included for comparison. Here a total torque of 2570 kg.cm. appears as a deflection downwards from a zero-line at the top, the upward deflection indicating a roll load of 12,550 kg.

The strong fluctuations of torque appearing on the other records may have two causes: Varying friction conditions on the strip and, irregularities in the mechanical parts of the rolling mill. The influence of the second factor can be studied separately by pressing the rolls together and running them without a strip between. The record, Fig. 1, obtained in this way, represents

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† Imperial Chemical Industries, Ltd., Plastics Division, Research Laboratories, formerly at The Cavendish Laboratory, Cambridge.

one of three tests which gave the same result. Here, the torque on each roll fluctuates with the period of the roll revolutions. This must be due to irregularities in the pinion-box gears, which produce speed variations of the two rolls. It will be shown in the Appendix that the universal joints cannot be responsible for the effect seen in Fig. 1. The Figure also shows that the torque

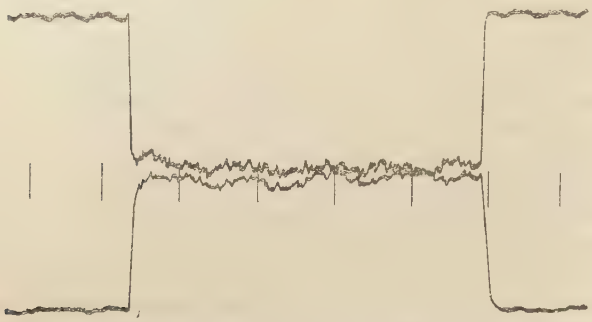


FIG. 2—Deflections with 99·5% aluminium strip, width 2·5 in., initial thickness 0·080 cm. Reduction 25%, rolls and strip dry

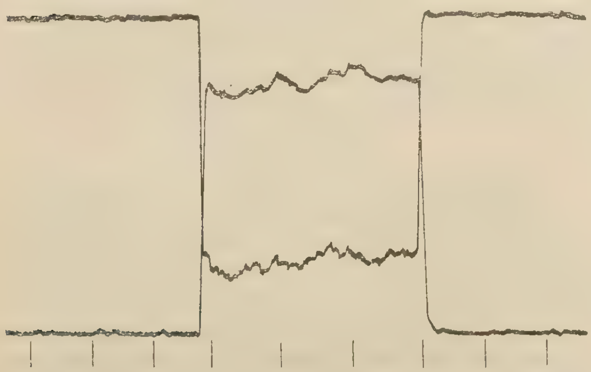


FIG. 3—Deflections with rimming-steel strip, 0·06% of C, 0·36% of Mn, width 2 in., initial thickness 0·137 cm. Reduction 13·2%, rolls and strip dry

on the lower roll (lower trace) increases gradually and is greater than the torque on the upper one, indicating that the lower roll diameter is slightly larger. The periodic variation of the relative velocity of the rolls must produce a fluctuating shear stress acting upon the strip in the direction of rolling. This may be responsible for waves in the strip or a wavy appearance of the surface finish. Records such as Fig. 1 provide a valuable test for the mechanical accuracy of a rolling mill.

Figures 2–7 show torque records for a number of different materials rolled without lubrication; explanatory data are given in the inscriptions to the figures. In all these records torque fluctuations with the period of the roll revolutions can be recognized; however, for different materials, and for consecutive passes of the same strip, they differ considerably in amplitude. Superimposed

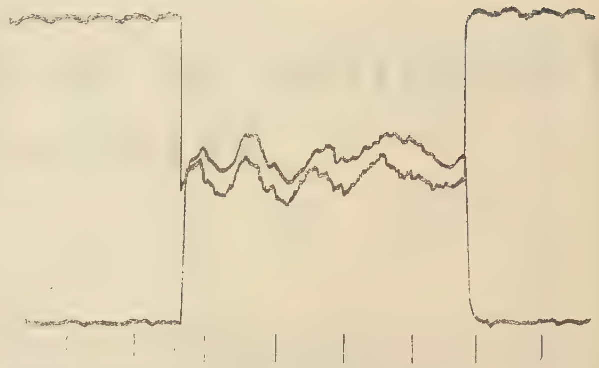


FIG. 4—Deflections with same strip as in Fig. 3, initial thickness 0·101 cm. Reduction 9·4%, rolls and strip dry

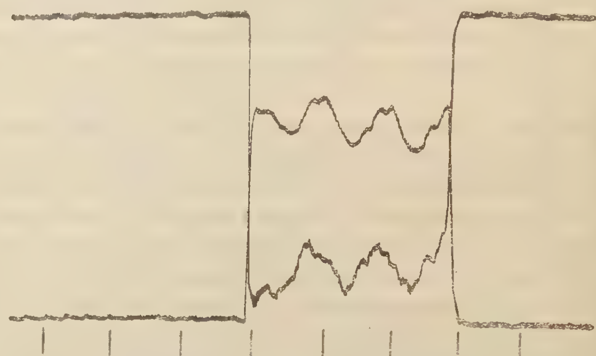


FIG. 5—Deflections with H.C. copper, width 2·5 in., thickness 0·3185 cm. Reduction 12·3%, rolls and strip dry

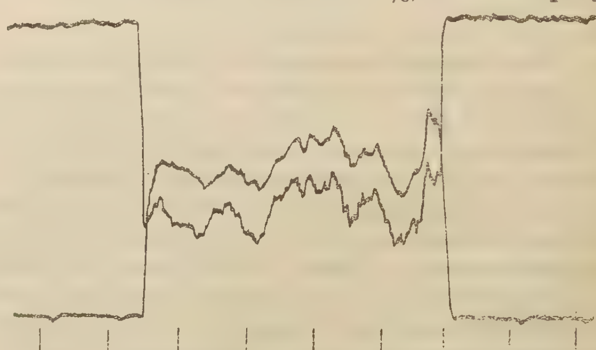


FIG. 6—Deflections with same strip as in Fig. 5, initial thickness 0·196 cm. Reduction 6·9%, rolls and strip dry

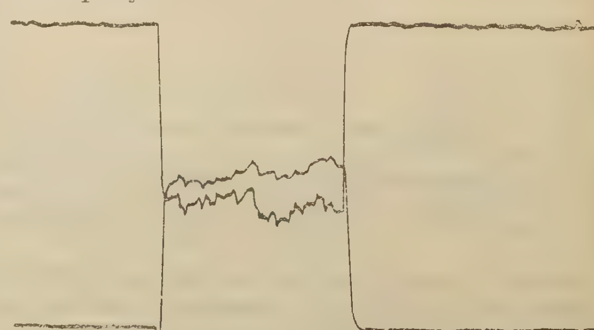


FIG. 7—Deflections with tellurium-lead strip, width 2 in., initial thickness 0·3515 cm. Reduction 52·5%, rolls and strip dry

on this effect we find irregular fluctuations of a shorter period on the torque records, indicating random variations of friction. As Figs. 9–11 show, such fast irregular fluctuations also occur if a roll lubricant is used. In our previous work mean values of a frictional coefficient had been determined from records like Fig. 8. The present records show that at any given point of the strip surface considerable deviations from this mean may occur.

Another conclusion from the present investigation concerns the measurement of the rolling torque. It is essential to measure the torque on both spindles simultaneously as only the sum of the two gives reliable information. Had only the torque on one roll been measured in the case of Fig. 11, and then been multiplied by two, an entirely erroneous numerical value for the total torque would have resulted.

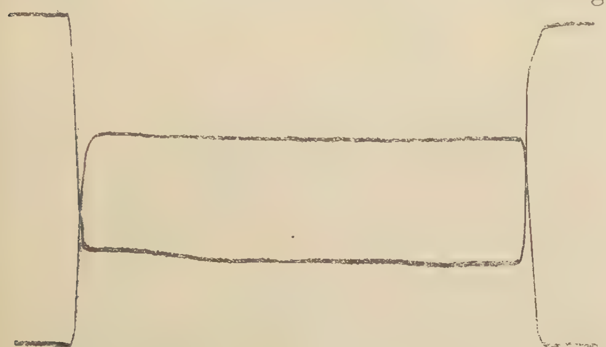


Fig. 8—Deflections with H. C. copper strip, width 2·5 in., initial thickness 0·124 cm., reduction 17·2%. Here the upward deflection records the roll separating force, the downward deflection the sum-torque on both spindles

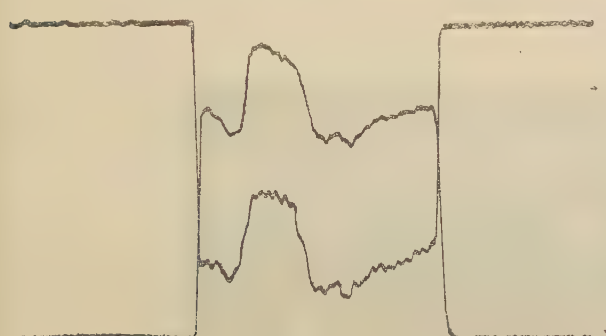


Fig. 9—Deflections with H. C. copper strip, width 2·5 in., initial thickness 0·1885 cm. Reduction 10·9%, gear oil lubricant

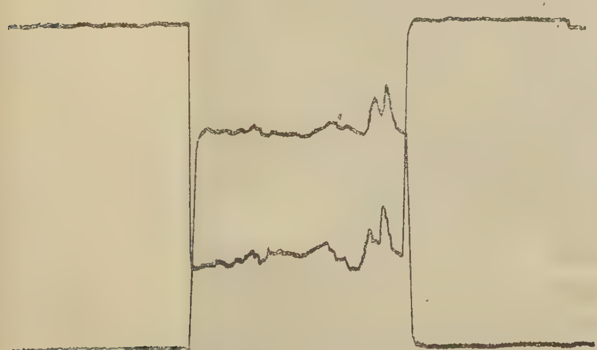


Fig. 10—Deflections with rimming-steel strip, 0·06% C, 0·36% Mn, width 2 in., initial thickness 0·157 cm. Reduction 15·2%; lubricant, rolling oil 546

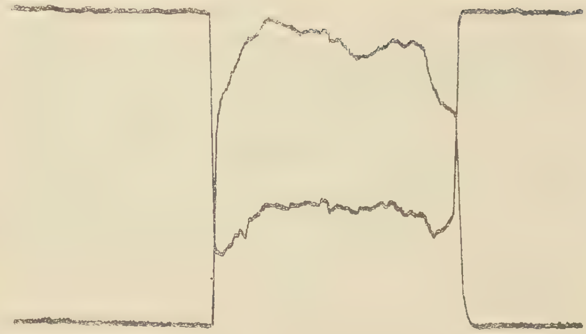


Fig. 11—Deflections with same strip as in Fig. 10, initial thickness 0·133 cm. Reduction 14·7%; lubricant, rolling oil 546

Figure 9 represents a record taken with strip which coiled around the upper roll during a part of the pass. The curving of the strip and the humps appearing on the record trace occurred at the same time. The strip here elongated more on the side facing the lower roll and consequently the lower roll performed the greater part of the work of deformation. Figure 10 was taken with a strip which, before rolling, had two sharp bends near its end, concave towards the lower roll. At the end of the record it can be seen that the lower roll required a much greater torque in working over these bends, because on the inside of the bend a longer contact arc was formed.

Appendix—*The Influence of the Universal Joints on the Torques Transmitted in the Spindles of a Rolling Mill*

The universal joints in our experimental rolling mill, connecting the spindles to the rolls on one side and to the pinion-box on the other, are equivalent to a Hooke joint. Let us consider a

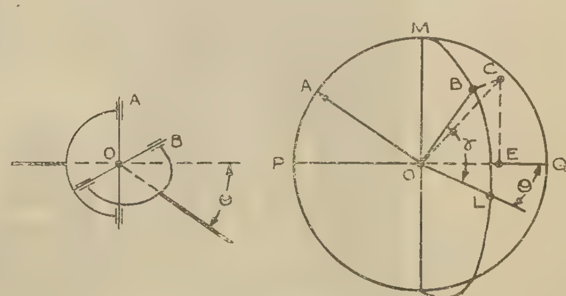


Fig. 12—The influence of the universal joints on the torques transmitted in the spindles of a rolling mill

joint near the pinion-box and let OA be the driving arm of the Hooke cross, rotating at constant angular velocity $\Omega_1 = d\alpha/dt$ in the plane $PMQN$ (where $\widehat{AOM} = \alpha$), Fig. 12. Let further OB, perpendicular to OA, be the driven arm rotating at the angular velocity $\Omega_2 = d\gamma/dt$ in the plane $MBLN$ which is inclined to the plane $MQNP$, at an angle θ. To find the relationship between γ and α consider OA and OB as of unit length and draw BC perpendicular to $PMQN$.

Then OC is perpendicular to OA, since the plane through BC and OB is perpendicular to OA.

$$\text{Therefore } \widehat{COE} = \alpha.$$

$$\text{Tan } \alpha = \frac{CE}{OE} = \frac{\sin \gamma}{\cos \gamma \,.\, \cos \theta},$$

$$\text{therefore } \tan \gamma = \tan \alpha \,.\, \cos \theta.$$

After differentiating this with respect to time, and eliminating γ we obtain :

$$\Omega_2 = \Omega_1 \,.\, \frac{\cos \theta}{\cos^2 \alpha + \sin^2 \alpha \,.\, \cos \theta}.$$

From this relationship we can at once find the torque T_2 acting in the spindle, since $T_1 . \Omega_1 = T_2 . \Omega_2$ must hold :

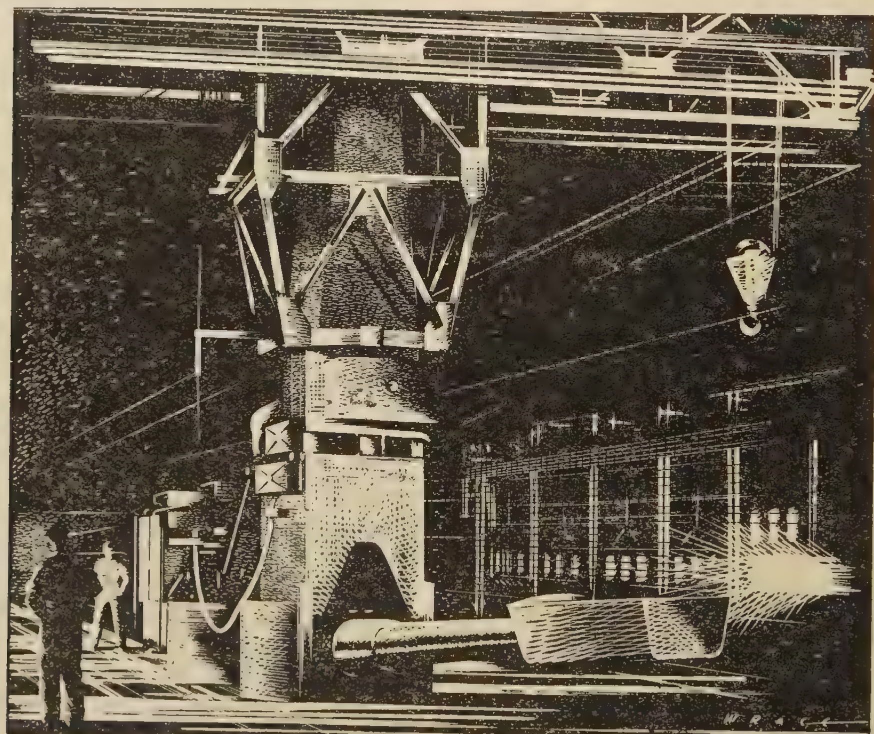
$$T_2 = T_1 \,.\, \frac{\cos^2 \alpha + \sin^2 \alpha \,.\, \cos^2 \theta}{\cos \theta}.$$

This relationship shows that the torque T_2 in the spindle oscillates twice between its maximum value $T_1/\cos\ \theta$ and minimum value $T_1/\cos\ \theta$ during one revolution of the pinion shaft. This proves that the torque fluctuations shown in Fig. 1 cannot be due to the universal joints. This point is further supported by a quantitative estimate. The inclination of the lower spindle in the experiment (the upper one was nearly in line) was $\theta = 2{\cdot}8°$. For $\theta = 3°$ we obtain :

$$T_2 \text{ (extreme)} = T_1 \pm 0{\cdot}14\%,$$

an amount too small to be observed.

There will also be a bending moment on the inclined spindle reaching a maximum of $T_1 \sin \theta$ (5% of the transmitted torque if $\theta = 3°$) twice during one cycle. This bending moment, however, is not recorded by our torquemeter as the four resistance strain gauges constituting it are so arranged on the spindles that the effect on two of the gauges exactly opposes the effect on the other two as far as the galvanometer current is concerned.



A Photographic Investigation of the Brightness Temperatures of Liquid Steel Streams*

By J. A. Hall, A.R.C.S., B.Sc., D.I.C.†

Synopsis

Cinematograph films have been taken of a range of steel streams from tapping and casting operations under such conditions as to enable an accurate density/temperature calibration of the film to be made, so that variations in brightness temperature of the steel surface can be investigated in relation to both time and space.

The effects of surface contamination and of the formation of partial black-body enclosures in the surface are discussed: the latter is found to be the most frequent cause of abnormally bright areas in the field of view. It is shown by laboratory experiment that an optical-pyrometer observer sighting on a flickering field or on the duller parts of a non-uniform field is likely to obtain a temperature value some 10° C. higher than that corresponding to the mean brightness of the part of the field which is being observed. This figure is in general agreement with the results obtained on tapping streams. With casting streams, good agreement has been obtained between the optical-pyrometer reading and the average photographic value of the brightness of a selected spot on the stream over a period of about a second. Under these conditions, about five out of six optical readings lie within ± 20° C. of the mean photographic value, while with tapping streams a similar proportion lies between 15° C. below and 35° C. above this figure.

It is shown that the use of a pyrometer employing a larger field of view than the normal disappearing-filament pyrometer (such, for example, as a photo-cell pyrometer) is not likely to introduce very serious differences. The reading will tend to be higher than that of the optical pyrometer, but the difference does not normally exceed 5° or 10° C.

The variations in surface brightness have been explored by plotting frequency curves of the distribution of brightness from a large number of spots on a single frame. In this manner it has been found possible to isolate the brightness corresponding to a clear metal surface with considerable accuracy.

In the future programme of work it is proposed to take certain additional precautions which have already suggested themselves in order to secure higher accuracy (especially to secure greater uniformity of exposure between successive frames of the film) and then to use the frequency-curve technique in order to make emissivity determinations on a range of steels, the true temperatures being determined by the "temperature-ring" thermocouple technique of Oliver and Land.

I—Introduction

In the course of an investigation into methods of measuring the temperature of liquid-steel streams, some experiments were made with a photo-cell type of pyrometer. Comparison with a normal disappearing-filament optical pyrometer showed that discrepancies were to be expected on account of the different sizes of the fields used by the two instruments, combined with the variations in brightness over the surfaces being observed. For example, in a casting stream there might be a bright streak which could be avoided by the user of an optical pyrometer but which would inevitably be included in the larger field

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† The National Physical Laboratory, Teddington.

of view of the photo-electric instrument. It was decided to explore this source of error photographically.

Photographic methods are not generally considered suitable for accurate photometry, but for the present purpose no other method could be used. Since, moreover, the brightness of a hot body varies very rapidly with temperature, a high degree of photometric precision is not required, and the photographic method offers the very great advantage of transferring the operation of measurement from the difficult surroundings of the melting-shop to the quiet of the laboratory with much more time in which to make observations. The analysis of the photographic records is, in fact, somewhat tedious and the method would hardly be suitable for routine work, but it was found that, by taking a number of precautions which are discussed fully in the Appendix, it was practicable to attain an absolute accuracy of temperature measurement comparable with that given by a portable disappearing-filament pyrometer. In addition, the method has the advantage that the temperature of each point in the whole field of view is recorded simultaneously while, by the use of very short exposures, it is possible to record features of a rapidly moving stream which are not visible to the eye.

Bright regions in a steel stream may be caused in two ways. (i) Slag or molten refractory material has a higher emissivity than clean metal, so, for example, the presence of slag in a tapping stream or products from the erosion of the nozzle in casting from a stopper ladle will lead to locally increased brightness. (ii) If the surface of the metal is irregular, hollows will act as partial black-body enclosures which will appear brighter than the open metal surface. It was hoped that, if cinematograph pictures of a number of streams were taken, the photographic analysis might make it possible to differentiate between these effects.

II—The Photographic and Sensitometric Techniques

The principle of the method employed was to place side by side, photographic images of the molten steel and of sources at known brightness temperatures, one of which would be nearly equal to that of the steel. A comparison of the image densities would thus enable the brightness temperature of the steel to be determined.

A 16-mm. cinematograph camera was used for the investigation. The method used was to mask off half the width of the film during the exposure of steel streams, and then to reverse the mask so as to put the reference standards of temperature on the other half of the film. These standards were provided by a gas-filled tungsten-strip lamp having a filament 3·2 mm. wide. The lamp was run at four brightness temperatures (approx. 1370°, 1440°, 1520°, and 1600° C.) so that a density/temperature calibration could be obtained, and the film was run through the camera four times in order to record them. An enlarged reproduction of a single frame of film is shown in Fig. 21. Since the resolving power of the emulsion is not sufficient to show the nick which marks the calibrated zone on the strip, it has been recorded by the use of an auxiliary marker lamp. This was an ordinary motor-car head-lamp bulb, somewhat under-run, of which a slightly reduced image was formed on the back of the strip and extending to one side of it at the position of the nick. This image was carefully focused by parallax so that its apparent position would not change with slight variations in the position of the camera.

The camera was a Paillard-Bolex, of which the film-track was modified during the course of the work in order to ensure maximum uniformity of running speed and freedom from scratching of the film, the latter point being of considerable importance when the negative was to be run through the camera at least five times.[1] The lens was a Ross Homocentric of f/5·6 aperture and 127 mm. focal length in a focusing mount which was carried by an extension tube screwed into the normal fitting of the camera turret. The extension tube was lined with black flock paper and, in order to cut down scattered light to a minimum, the lens was fitted with a hood 60 mm. long and 28 mm. in diameter, similarly lined. As only a small aperture was required, and it was important that the distance between stop and film should not change with any focusing adjustment, the lens stop was always set at full aperture and a small fixed stop was placed behind the focusing mount. The camera was run at a speed of 24 frames/sec., and when the normal shutter, having an opening of approximately 190° was used, the stop was 1·75 mm. dia. at a distance of 112 mm. from the film. In some of the experiments, in order to arrest the movement of the steel more completely, a special shutter having an opening of only 12° was used, and a stop of 7 mm. dia. was substituted in order to give approximately the same exposure. The same shutter and stop combination which had been used to photograph the steel was, of course, always used to photograph the corresponding strip-lamp images. A filter of 5·7 mm. thickness of Corning 150%-red glass was used over the lens. This is a filter with somewhat higher transmission than that used in the standard optical pyrometer of

the National Physical Laboratory which had been used to calibrate the tungsten-strip lamp (*see* Appendix section (v)).

The film used was Ilford H.P. 3 negative, which has a high-speed panchromatic emulsion, and it was developed for 6½ min. at 19° C. in Johnson's Constant Endura developer by the rack and tank method. This technique gives a gamma* of about 0·8 for the part of the characteristic normally used in these experiments. The developing tank held 12 gal. of solution and the racks, which were designed to accommodate 100 ft. of 35-mm. film, measured 2 ft. 6 in. from the top to the bottom rail. The edge of the film was notched after development at the crossings of the top rail of the rack, so that any inequalities in development could be correlated with position in the rack. Drying was carried out on a revolving drum and was completed in about 20 min.

The film densities were measured on a modified Moll microphotometer. The travelling carriage which holds the film was fitted with two calibrated screws at right-angles, so that the density distribution over a series of pictures could be completely explored. A barrier-layer photo-cell in a Campbell-Freeth measuring circuit was used as detector in place of the thermocouple, so that much greater sensitivity could be obtained. Normally, a scanning spot 0·1 mm. square was used, and the density of the steel image was observed over an area of 0·3 × 0·2 mm. by taking the mean of a set of six readings. The narrow strip-lamp images were observed by taking a series of overlapping spots, spaced at 0.02-mm. intervals across the image. The density was taken from the mean of the four or five central readings which did not show serious variations.

A photographic emulsion has a more or less linear characteristic when density ($= \log_{10}$ opacity, $= \log_{10}(1/\text{transmission})$) is plotted against log brightness. Hence, as the logarithm of the brightness of a grey body at a given wave-length is proportional to 1/temp. (° K.), this function should yield an approximately straight line when plotted against the density obtained on the film.

No photographic emulsion, however, has an ideally straight-line characteristic. For a given time of exposure, the slope of the characteristic ($dD/d\,(\log B)$ = gamma) increases with the illumination at low intensities (under-exposure), then remains fairly constant (correct exposure) and falls off again at high intensities (over-exposure). Full contrast is thus only secured by correct exposure, and, since the microphotometer is most sensitive at low densities, the best results are obtained in the region where the curve of under-exposure merges into the approximately straight line of correct exposure. Figure 1 (*a*) shows the curvature of the part of the characteristic which has been used in the present work.

* Slope of the density *versus* log intensity characteristic of the emulsion (*see* later).

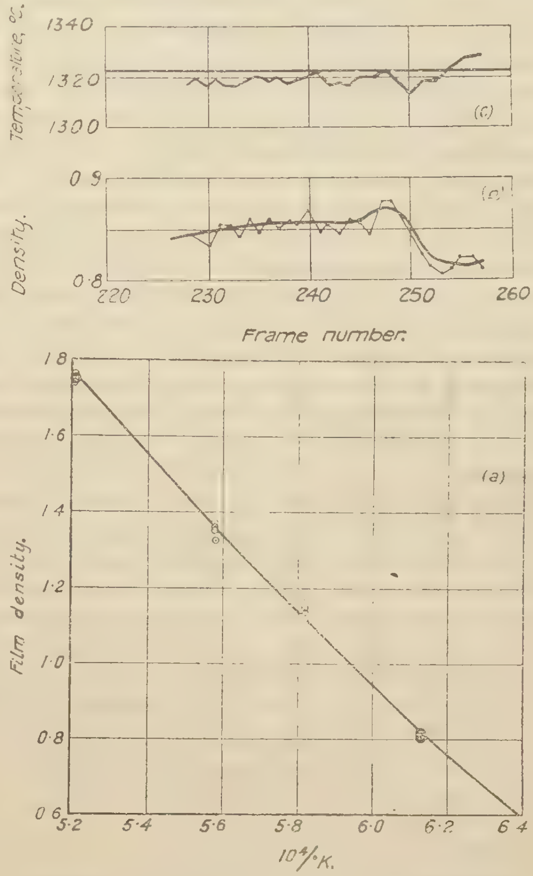


Fig. 1—Calibration Curves of film

It is clear that the four strip-lamp images recorded on the temperature-measurement films are not sufficient (having regard to the experimental errors) to define the shape of the characteristic curve. An extended calibration was therefore made, using seven images distributed over the whole picture-space, and covering a temperature range of 1280° to 1780° C. (density 0·65 to 1·95). The best mean curve was drawn through the observed points and a celluloid template was cut to match it. On this template the inertia point (the intercept made by the straight-line portion of the characteristic when produced to meet the $D = 0$ axis) was marked. In the present work all density measurements are referred to the clear glasses between which the film was sandwiched in the microphotometer. On this basis the fog density was about 0·4, of which about 0·25 is accounted for by the tinted base of the film. The inertia point was therefore taken on the $D = 0{\cdot}25$ line.

The method of applying the calibration to a particular shot was as follows :

On the first four frames examined the densities of all four strip-lamp images were measured, while on the remainder only that strip-lamp image which was nearest in density to that of the image of the steel was used. Using the celluloid template made from the extended calibration curve, a mean curve was put through the observations of the strip-lamp images on the first four frames. In this operation the inertia point marked on the template was placed on the line $D = 0 \cdot 25$. This procedure would not lead to an accurate result if the slope of the curve were widely different from that of the extended calibration, as it would involve an appreciable tilting of the log-intensity axis and hence of the foot of the curve. As densities less than 0·7 were not used, and the variations in slope of the curves for different shots, even on different reels of film, were slight, the method is sufficiently accurate for interpolation purposes.

Since neither film sensitivity nor development can be assumed to be constant along the length of the film, the density of each steel image is related to that of a selected strip-lamp image on the same frame. The densities of the images of this strip lamp are plotted against their frame numbers, and a mean curve is drawn. Figure 1 (*a*) shows a typical calibration curve, and above it, Fig. 1 (*b*), the curve of variation in density of the image of the strip lamp run at the lowest temperature (SL_1) over a length of 30 frames. The observed value of the density of each steel image is then corrected by an amount equal to the difference between the density of the strip lamp image on the same frame and the mean of the four values of the density of the same strip lamp which were used in drawing the density/temperature calibration curve. For example, in Fig. 1 (*b*), the density of SL_1 taken from the mean curve is 0·870 at frame 247, while the mean of the four spots representing SL_1 on the calibration curve is 0·817. The observed value of the steel density on frame 247 must therefore be reduced by 0·053 if the calibration curve is to apply.

An additional correction is also applied to the steel density on account of the fact that there is a characteristic density pattern over the surface of each frame of film when exposed to an evenly

TABLE I—*Specimen Reduction of Observations*

Reel 30, shot 7, frame 2131

X and Y are measured in mm. from the left-hand edge of the film and the upper edge of the bottom left-hand sprocket-hole respectively (*see* Fig. 65).

Image.	Position in Frame.		Microphotometer Reading, microvolts.	Reduction of Observations.
	X.	Y.		
Datum	6·90	16·59	...	...
Clear glass			36520	...
SL_1	17·42	21·53	(7860)	
,,	17·44	,,	(7480)	
,,	17·46	,,	(7440)	
,,	17·48	,,	7230	Observed density $\left(\log_{10}\frac{36355}{7142}\right)$ ... ... 0·707
,,	17·50	,,	7050	Corresponding density from mean curve ... 0·710
,,	17·52	,,	7070	Mean density of calibration observations ... 0·715
,,	17·54	,,	7220	
,,	17·56	,,	(7320)	Correction to steel density ... ... +0·005
,,	17·58	,,	(7790)	
			Mean 7142	
Steel	12·40	21·29	6880	
,,	12·50	,,	6830	Observed density ... ... 0·736
,,	12·60	,,	6100	Correction (*see* above) ... ... +0·005
,,	12·40	21·39	7190	Density distribution correction ... ... +0·013
,,	12·50	,,	6770	
,,	12·60	,,	6350	Corrected density ... ... 0·754
			Mean 6687	10^4/temp. (° K.) ... ... 6·120
Clear glass			36190	Temperature ... ... 1361° C.

illuminated test object (*see* Appendix, section (ii)). For this reason a density on one part of the frame cannot, without the application of a correction, be related to a standard density in another part of the same frame.

The uppermost curve, Fig. 1 (*c*), shows the photographic determination of the temperature of a strip lamp run at a temperature of 1323° C. The image was enlarged by means of a supplementary lens so that it corresponded closely both in size and position in the frame with a normal casting-stream image. The agreement between the photographically determined temperature and the known brightness temperature is to within ± 10° C. at any isolated point, or ± 5° C. when the mean of the whole run is considered. The density and temperature scales on the two upper curves (Fig. 1 (*b* and *c*)) are approximately equivalent, and the apparent rise in temperature of the "imitation steel" strip lamp after frame 250 suggests that the allowance for the fall in density of SL_1 from this point is excessive (*cf.* Table II, line 3).

A typical series of observations on a single frame of film is given in Table I.

Table II gives a list of the sources of error which have been considered. As a result of the experiments detailed in the Appendix an estimate has been made of the residual magnitudes of the errors, and these values are also given in Table II.

From the above it is clear that the worst error is to be expected in the absolute accuracy given by an observation at a point in an individual frame. This might, if all the errors happened to be at a maximum and of the same sign, amount to ± 20° C. The corresponding error for the mean value taken from a series of frames is ± 10° C. Since these values are derived from six and five independent sources respectively, it may be assumed that such errors will occur but rarely, and a fair estimate of the two accuracies would probably be ± 15° C. and ± 7° C. respectively.

III—The Observations

All the observations were made in comparison with readings on an optical pyrometer taken by an experienced observer. The optical pyrometer was a Leeds and Northrup potentiometric instrument which was calibrated in February, 1945, at the National Physical Laboratory. The corrections determined in this calibration were considered reliable to ± 5° C. and were in good agreement with those which had previously been determined by Messrs. Hadfields, Ltd., who lent the instrument and the services of an observer for the present work. The mean effective wavelength of the red glass used in this pyrometer is approximately the same as that of the National Physical Laboratory standard pyrometer used for the calibration of the strip lamp.

Four people were employed in taking the observations: Optical pyrometer observer, cameraman, timekeeper-recorder, and second timekeeper. The timekeeper-recorder used an accurate stopwatch (10-sec. dial) and also booked the observations, while the second timekeeper used an ordinary watch with a seconds hand, recording the approximate time of each stage in the observations, normally beginning with the taking of an immersion-thermocouple reading before the furnace was tapped. Since the accuracy of the photographic observations depends on a knowledge of the camera speed the runs were timed by a standardized procedure which was adopted for the recording of steel and strip-lamp images, so as to eliminate personal errors as far as possible.

Table II—*Effect of various Sources of Error*

Source.	Estimated Residual Error.			
	Absolute Value from Individual Frame, ° C.	Absolute Values from Mean of a Series of Frames, ° C.	Differences between Points in same Frame, ° C.	Differences from Frame to Frame at same Point, ° C.
(i) Variation in exposure time	±6	±3	0	±3
(ii) Irregularity in illumination and development of individual frames	±3*	±1*	±3	±3
(iii) Irregularity of development and sensitivity along film	±5	negligible	0	±5
(iv) Time interval between observation and calibration	±3*	±3*	0	0
(v) Difference in mean effective wavelength ...	0	0	0	0
(vi) Uncertainty in drawing calibration curve ...	±2†	±2†	0	0
(vii) Errors in density measurement	±1	±1	±1	±1

* Rather greater for reels 18 to 25.
† Rather greater for reel 24.

The footage indicator of the camera was read (so that the strip-lamp images could be placed sufficiently accurately alongside the steel images) and the camera on its tripod was sighted on the desired point. The optical-pyrometer observer watched the stream and, when he considered that conditions were becoming satisfactory, called, "*start*." The camera and the stop-watch were started on this signal. When the observer was satisfied with his adjustment of the optical pyrometer (usually after about 2 sec.) he called, "*now*," and the timekeeper noted this time as accurately as possible by the moving hand of the stop-watch. The cameraman continued the run for a few seconds more—until a total of about 6 sec. had elapsed—and then called, "*stop*," as he released the camera button. On this signal the stop-watch was stopped and the time of the run recorded. A length of about 2 ft. of film was run off with the lens covered and the camera was fully wound ready for the next observation.

When the strip-lamp images had been applied to the film, it was left for several days to minimize risk of changes in the latent image in the period immediately following exposure (*see* Appendix, section (iv), for further details of this source of error) and then developed. The frames in each reel of film were then numbered serially, the number of frames in each run on the steel and the four strip-lamp images were counted and the camera speeds calculated.

The frame number corresponding in time to each call of "*now*" was then determined. This of course, could only be done to an accuracy of about $\pm$ 5 frames, owing to the fact that the time was only observed by the moving hand of the stop-watch. A print of the film was made, and this was examined by the optical-pyrometer observer, who made a special study of it in the neighbourhood of the "*now*" calls, near each of which he selected a frame which corresponded, as nearly as he could say, with the appearance of the stream when he took his reading. This frame is referred to as the "selected frame." Further, he indicated the spot where he would have taken his reading in terms of its X and Y co-ordinates. The filament of the Leeds and Northrup pyrometer has a width of $0 \cdot 04$ mm. and it was thought that an area of $0 \cdot 3 \times 0 \cdot 2$ mm. measured at the filament could be picked out by the observer for measurement. The focal lengths of the objectives of the camera and the pyrometer are approximately the same, so six microphotometer readings were made on the film negative in a rectangular group covering an area $0 \cdot 3 \times 0 \cdot 2$ mm. around the selected point. Subsequent experiments (described in section IV) modified considerably the opinion on which this procedure was based.

Figure 22 is a photograph of a test object representing a casting stream 2 in. wide at a distance of 11 ft. It was taken through the optical pyrometer in order to show the appearance of such a field to the eye of the observer. The dark line extending across the field of view is the straight filament of the pyrometer, while the other line is the marker in the lamp which serves to indicate the calibrated point of the filament. The width of the "stream" at this distance is such as to give an image 2 mm. wide on the film record. All the enlargements of film frames are reproduced on the same scale, so that if it is desired to study more closely the appearance of these frames as they would be seen through the pyrometer, this can be done by tracing the filament and marker image from Fig. 22 on to a piece of celluloid and superposing it on the frame to be examined.

For the first analysis of the films, runs of 30 frames immediately preceding the selected frame in each shot were examined.* Each of these runs covers a period of $1 \cdot 3$ sec. during which the observer was adjusting the balance of the pyrometer. In the later observations on casting streams the number of frames examined was reduced to 20, since the temperature variations with time were not then as marked as they were in tapping streams.

The results obtained with nine typical casting streams are shown in Figs. 2–10. Figs. 2–10 (*a*) represent the change in brightness with time of the small area around the selected point. The full-line curve relates to the $0 \cdot 3 \times 0 \cdot 2$ mm. area, while the broken line gives the result obtained by the use of a circular patch $0 \cdot 6$ mm. in dia., corresponding approximately with the area which would be covered by an experimental photo-electric pyrometer which is now under construction. The $0 \cdot 3 \times 0 \cdot 2$ mm. area is marked in outline on each photograph. The point marked with a cross is the optical-pyrometer reading and is placed to correspond as nearly as possible in time with the signal "*now*." The selected frame is indicated by a small circle. The reference to the shot, *e.g.*, reel 18, shot 3, is given.

The curves in Figs. 2–10 (*b* and *c*) are traverses through the selected point in two directions at right-angles, the horizontal traverse being on the left (*b*). The X and Y co-ordinates are stated in millimetres on the film (or at the pyrometer filament), corresponding roughly with inches on the stream when this is observed at a distance of

* In certain instances, as a result of inaccurate placing of the strip-lamp images on the film, the run of 30 frames had partly to follow instead of precede the selected frame.

10 ft., which was about the average with the casting streams. The position of the selected point is marked by arrows on the traverses and a similar arrow on the time/temperature curve indicates the frame on which the traverses were taken. In some instances the stream passes right across the frame and the exact portion of it which is in view cannot therefore be defined. Where the upper end of the stream is visible on the frame it has been marked on the curve by *L* (ladle). Correspondingly, the lower end is marked *M* (mould) except that when a runner-box was used, the position of the top of the box is indicated by the letter *R*.

Enlargements of frames from those runs which show any features of interest are reproduced in Fig. 23. Normally the frame which has been enlarged is the selected frame, but in certain instances another frame has been used. When this has been done, the frame has been indicated on the graph by a triangle.

Similar results for tapping streams are shown in Figs. 11–20, and the corresponding photographs in Fig. 24. Here, traverses of the streams have only been made in a few instances, in each case approximately at right-angles to the direction of flow. This involves either a vertical or diagonal traverse, indicated on the graph by "*Y*" or "*Diag.*" respectively.

It was apparent from the shots already mentioned (Fig. 24 (*b*) provides a good example) that the movement of the streams was too rapid to permit the recording of detailed structure by the normal film technique. Moreover, owing to the blurring of the image, the temperature differences from frame to frame—large as they were—were probably being minimized. To use a high-speed camera would have involved an unnecessary expenditure of film and would have made it very difficult to secure an accurate calibration. The special shutter mentioned in section II was therefore fitted to the camera so that the exposure time could be reduced from 20 to 1·3 milliseconds, while still maintaining the normal frequency of 24 frames/sec. Some of the results obtained by this technique are shown in Figs. 27–37 for tapping streams and Figs. 38–46 for casting streams, together with the corresponding photographs, Figs. 25 and 26. The conditions to which the curves of Figs. 2–20 and 27–46 relate are set out in Tables III–VI. In the graphs will be found certain curves additional to those mentioned above, which are those which were taken as standard practice. The extra curves were taken to elucidate special points that arose during the analysis and will be discussed in section V.

It was noticed in the earlier experiments that when there was a large discrepancy between the values given by the optical pyrometer and those given by the film, the optical reading was almost invariably higher than that recorded photographically. In view of this fact, laboratory experiments were carried out to investigate the effect of (*a*) flicker and (*b*) the presence of neighbouring areas of increased brightness, on the accuracy of setting of the optical pyrometer.

IV—Optical Pyrometry of Flickering and Non-Uniform Fields

In the laboratory experiments with flickering and non-uniform fields, the portable standard optical pyrometer of the National Physical Laboratory was used. This instrument has a filament of approximately the same width (0·04 mm.) as that of the Leeds and Northrup pyrometer used in the steel works.

The first experiment was made with a field which alternated in brightness between apparent temperatures of 1392° and 1509° C.; a change somewhat greater than that caused by the passage of pieces of slag across a liquid-steel surface. The apparatus was set up as shown in Fig. 47. The two strip lamps (SL_D and SL_F) were fed from a storage battery and connected in series, and with SL_F obscured, the current was adjusted until the apparent brightness temperature of SL_D, viewed through the semi-platinized mirror, was about 1400° C. The sector disc was then rotated so as to uncover SL_F and its image was adjusted to coincidence with that of SL_D. The combined brightness of the two strip lamps was then adjusted to approximately 1500° C. by means of a step wedge adjacent to the sector disc. Accurate measurements of these two apparent temperatures were then made. A sector disc having six openings totalling 50% transmission was then rotated in front of SL_F so as to give frequencies of flicker of from 5 to 320 cycles/sec. and the apparent temperature of the field was measured at each frequency.

The results are plotted in Fig. 48. The temperature axis has been divided on a uniform scale of brightness, and the line marked 50% is the mean between the minimum and maximum brightnesses (SL_D and $SL_D + SL_F$). Even at frequencies as high as 160 cycles/sec., the settings by both observers were higher than this mean value by about 5° C. and this increase became about 10° C. for frequencies between 10 and 40 cycles/sec. When the frequency was as low as 5 cycles/sec., the setting became very much a matter of personal opinion. One observer (V.M.L.) maintained much the same settings as at a frequency of 10 cycles/sec., while the other (J.A.H.) obtained a value some

TABLE III—*Conditions under which Observations Were Made*

Casting streams, photographed with 20 millisecond exposures

<table>
<tr><th colspan="2">Run.</th><th rowspan="2">Figure Nos.</th><th colspan="2">Steel.</th><th rowspan="2">Casting Method.</th><th rowspan="2">Time of Shot.</th><th rowspan="2">Observer's Remarks.</th></tr>
<tr><th>Reel.</th><th>Shot.</th><th>Composition.</th><th>Furnace.</th></tr>
<tr><td>18</td><td>3</td><td>2, 23 (a)</td><td>2·5% Ni, 0·4 % Cr, 0·7% Mo</td><td>5-ton basic arc</td><td>Runner box, 2½-in. nozzle.</td><td>1st ingot, 7 sec. after start.</td><td>Good stream with very few visual slag specks.</td></tr>
<tr><td>33</td><td>11</td><td>3,</td><td>0·75% Cr</td><td>15-ton basic arc</td><td>Upcast, 1¾-in. nozzle.</td><td>End of last plate.</td><td>...</td></tr>
<tr><td>34</td><td>9</td><td>4, 23 (b)</td><td>0·76% C, 0·40% Mn, 0·37 % Si, 4·36% Cr, 18·6% W, 1·37 % V, 0·66% Mo</td><td>2-ton basic arc</td><td>Cast through "temperature ring."</td><td>End of last plate</td><td>Thermocouple in ring read 1503°C.</td></tr>
<tr><td>20</td><td>1</td><td>5, 23 (c)</td><td>0·75 % C, 0·9 % Mn, 1·0 % Cr</td><td>30-ton acid open-hearth</td><td>Direct, 1-in. nozzle (20-ton ingot).</td><td>3 min. from start.</td><td>Slag streak in centre.</td></tr>
<tr><td>20</td><td>5</td><td>6, 23 (d)</td><td>,,</td><td>,,</td><td>,,</td><td>7 min. from start.</td><td>Smoke, slag streak splitting.</td></tr>
<tr><td>20</td><td>10</td><td>7, 23 (e)</td><td>,,</td><td>,,</td><td>,,</td><td>10 min. from start.</td><td>Good stream.</td></tr>
<tr><td>22</td><td>11</td><td>8, 23 (f)</td><td>2·0% Si</td><td>30-ton acid open-hearth</td><td>Upcast, 2-in. nozzle.</td><td>17 min. from start.</td><td>Rapid erosion of nozzle.</td></tr>
<tr><td>23</td><td>7</td><td>9, 23 (g)</td><td>0·2–0·4 % C</td><td>80-ton basic open-hearth</td><td>Upcast, 1¾-in. nozzle.</td><td>2nd plate.</td><td>Patch of slag.</td></tr>
<tr><td>25</td><td>1</td><td>10</td><td>0·5–0·55% C (for wire)</td><td>80-ton basic open-hearth</td><td>Upcast, 1½-in. nozzle.</td><td>Start of 1st plate.</td><td>Good stream, some fumes.</td></tr>
</table>

TABLE IV—*Conditions under which Observations Were Made*

Tapping streams, photographed with 20 millisecond exposures

<table>
<tr><th colspan="2">Run.</th><th rowspan="2">Figure Nos.</th><th colspan="2">Steel.</th><th rowspan="2">Immersion Thermocouple Reading, ° C.</th><th rowspan="2">Bath Additions.</th><th rowspan="2">Time of Shot.</th><th rowspan="2">Observer's Remarks.</th></tr>
<tr><th>Reel.</th><th>Shot.</th><th>Composition.</th><th>Furnace.</th></tr>
<tr><td>18</td><td>5</td><td>11, 24 (a)</td><td>0·5% C, 2·0% Ni, 2·0% Cr</td><td>10-ton basic arc</td><td>1560</td><td>...</td><td>Start of tapping (5 min. after thermocouple reading).</td><td>Appreciable amount of slag.</td></tr>
<tr><td>33</td><td>1</td><td>12</td><td>0·75% Cr</td><td>15-ton basic arc</td><td>1575</td><td>None</td><td>Start of tapping.</td><td>...</td></tr>
<tr><td>34</td><td>8</td><td>13, 24 (b)</td><td>0·76%C, 0·40% Mn, 0·37% Si, 4·36%Cr, 18·6% W, 1·37% V, 0·66% Mo</td><td>2-ton arc</td><td>...</td><td>...</td><td>Start of tapping.</td><td>...</td></tr>
<tr><td>19</td><td>3</td><td>14, 24 (c)</td><td>0·75% C, 0·9% Mn, 1·0% Cr</td><td>30-ton acid open-hearth</td><td>...</td><td>...</td><td>1¾ min. from start.</td><td>Smoke.</td></tr>
<tr><td>19</td><td>4</td><td>15, 21</td><td>,,</td><td>,,</td><td>...</td><td>...</td><td>5¼ min. from start.</td><td>Quite a good stream.</td></tr>
<tr><td>19</td><td>11</td><td>16</td><td>,,</td><td>,,</td><td>...</td><td>...</td><td>8 min. from start.</td><td>Slag.</td></tr>
<tr><td>21</td><td>7</td><td>17</td><td>2·0% Si</td><td>30-ton acid open-hearth</td><td>...</td><td>...</td><td>4½ min. from start.</td><td>Dark streak near bottom of field.</td></tr>
<tr><td>24</td><td>1</td><td>18</td><td>0·50–0·55% C (for wire)</td><td>80-ton basic open-hearth</td><td>1588</td><td>...</td><td>Start of tapping.</td><td>Very thin tapping stream; fairly uniform.</td></tr>
<tr><td>24</td><td>2</td><td>19</td><td>,,</td><td>,,</td><td>,,</td><td>...</td><td>¾ min. later.</td><td>Very thin but good stream.</td></tr>
<tr><td>23</td><td>5</td><td>20, 24 (d)</td><td>0·20–0·24% C</td><td>80-ton basic open-hearth</td><td>1594</td><td>...</td><td>End of tapping.</td><td>Slag.</td></tr>
</table>

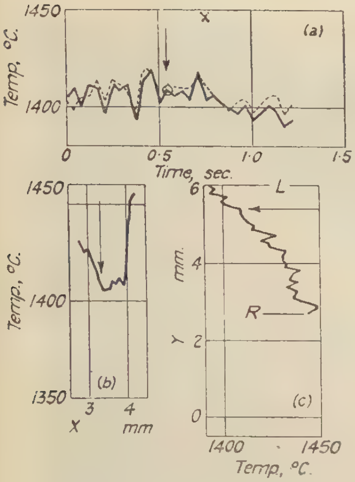


FIG. 2—Reel 18, shot 3 (*see* Fig. 23 (*a*))

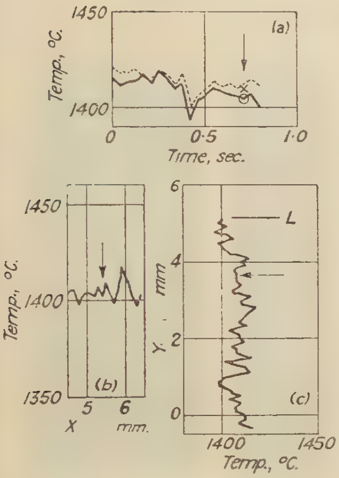


FIG. 3—Reel 33, shot 11

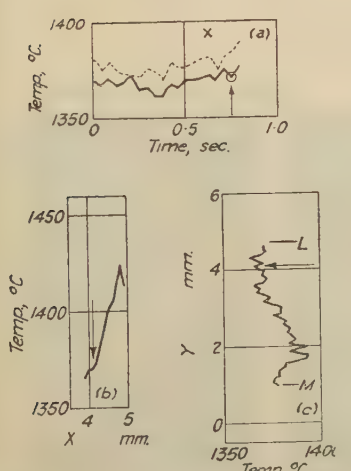


FIG. 4—Reel 34, shot 9 (*see* Fig. 23 (*b*))

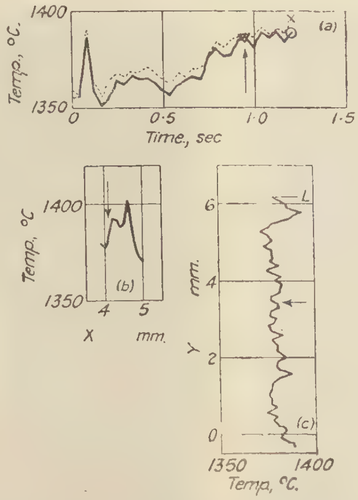


FIG. 5—Reel 20, shot 1 (*see* Fig. 23 (*c*)). Same heat as Figs. 6 and 7

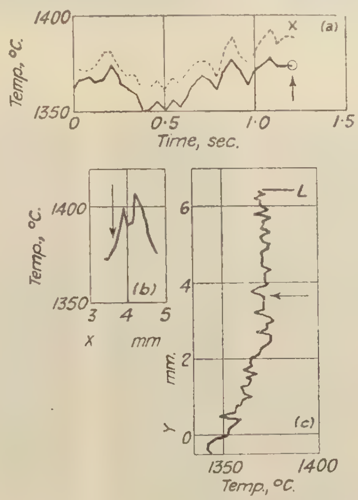


FIG. 6—Reel 20, shot 5 (*see* Fig. 23 (*d*)). Same heat as Figs. 5 and 7

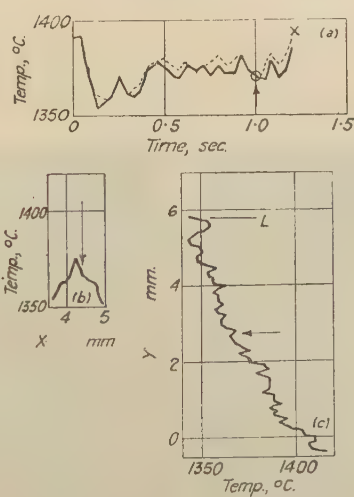


FIG. 7—Reel 20, shot 10 (*see* Fig. 23 (*e*)). Same heat as Figs. 5 and 6

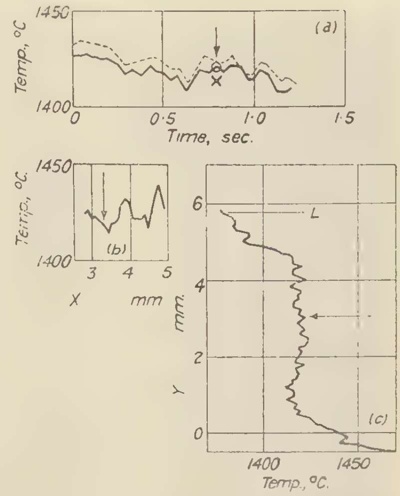


FIG. 8—Reel 22, shot 11 (*see* Fig. 23 (*f*))

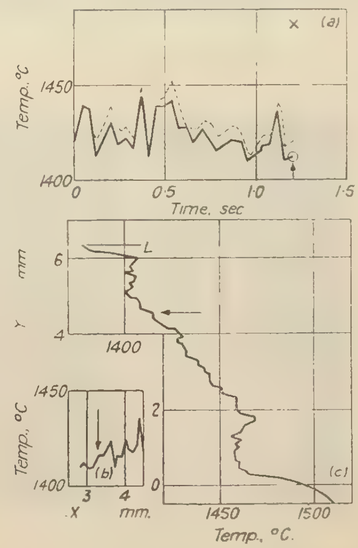


FIG. 9—Reel 23, shot 7 (*see* Fig. 23 (*g*))

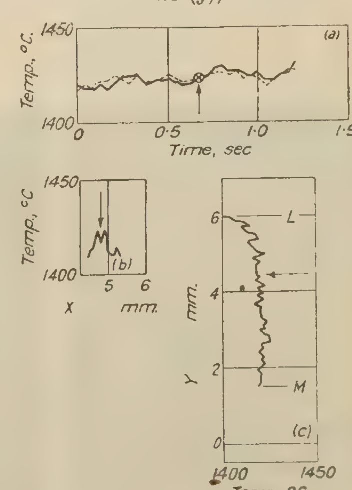


FIG. 10—Reel 25, shot 1

Figs. 2–10—Casting streams, 20 milliseconds exposure

(**L** = ladle, **M** = mould, **R** = runner box; **X** = optical reading, **O** = selected frame, and ∇ = frame enlarged)

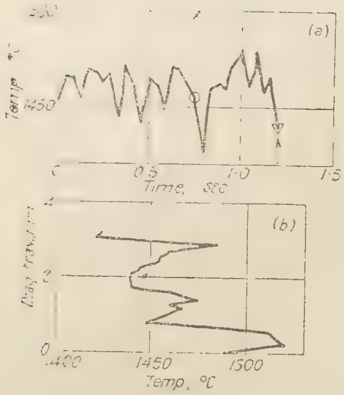


Fig. 11—Reel 18, shot 5 (*see* Fig. 24 (*a*))

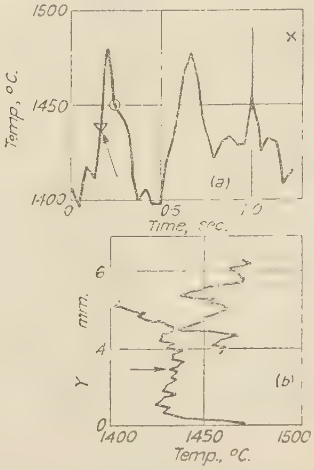


Fig. 14—Reel 19, shot 3 (*see* Fig. 24 (*c*)). Same heat as Figs. 15 and 16

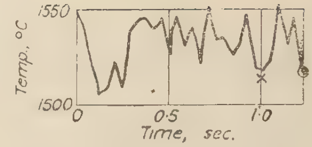


Fig. 17—Reel 21, shot 7

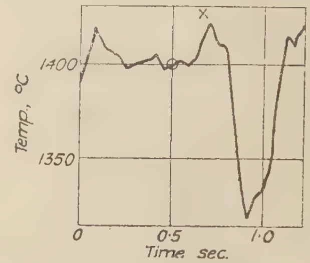


Fig. 18—Reel 24, shot 1. Same heat as Fig. 19

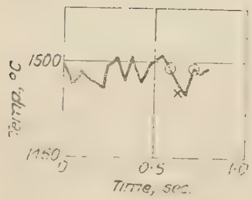


Fig. 12—Reel 33, shot 1

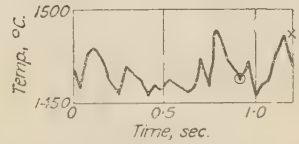


Fig. 15—Reel 19, shot 8 (*see* Fig. 24 (*c*)). Same heat as Figs. 14 and 16

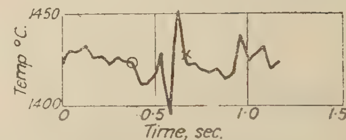


Fig. 19—Reel 24, shot 2. Same heat as Fig. 18

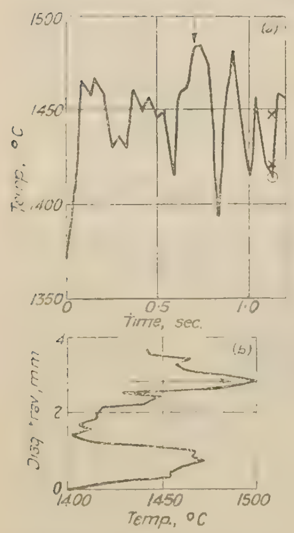


Fig. 13—Reel 34, shot 8 (*see* Fig. 24 (*b*))

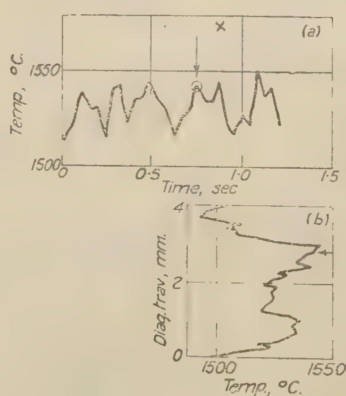


Fig. 16—Reel 19, shot 11. Same heat as Figs. 14 and 15

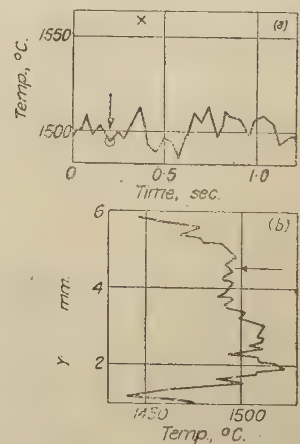


Fig. 20—Reel 23, shot 5 (*see* Fig. 24 (*d*))

Figs. 11–20—Tapping streams, 20 milliseconds exposure

(L = ladle, M = mould, R = runner box; X = optical reading, O = selected frame, and ∇ = **frame enlarged**)

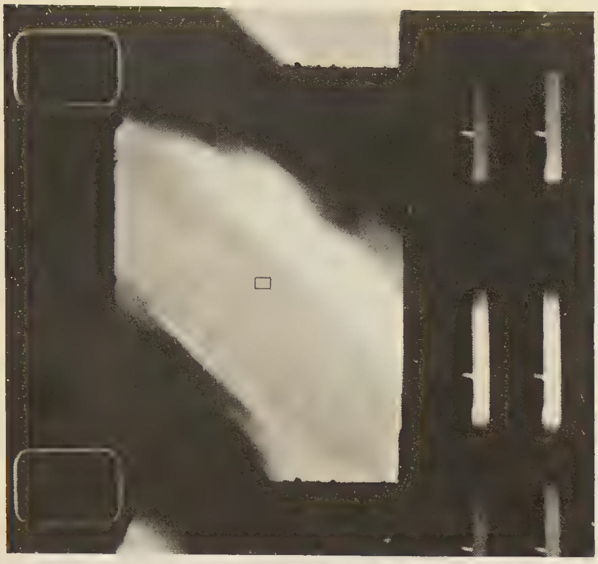


FIG. 21—Enlargement of typical frame of film ; reel 19, shot 8 (*see* Fig. 15)

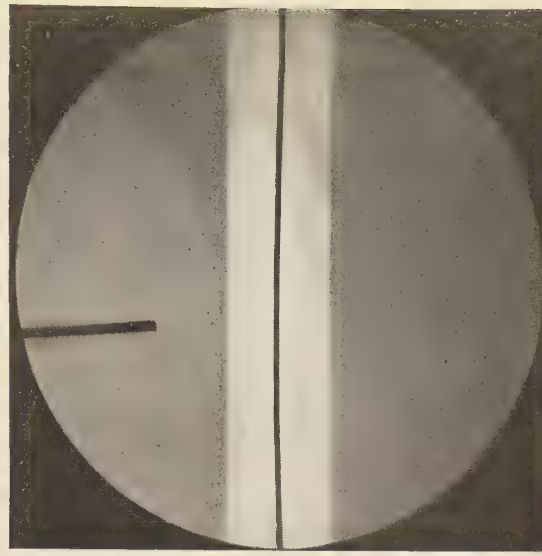
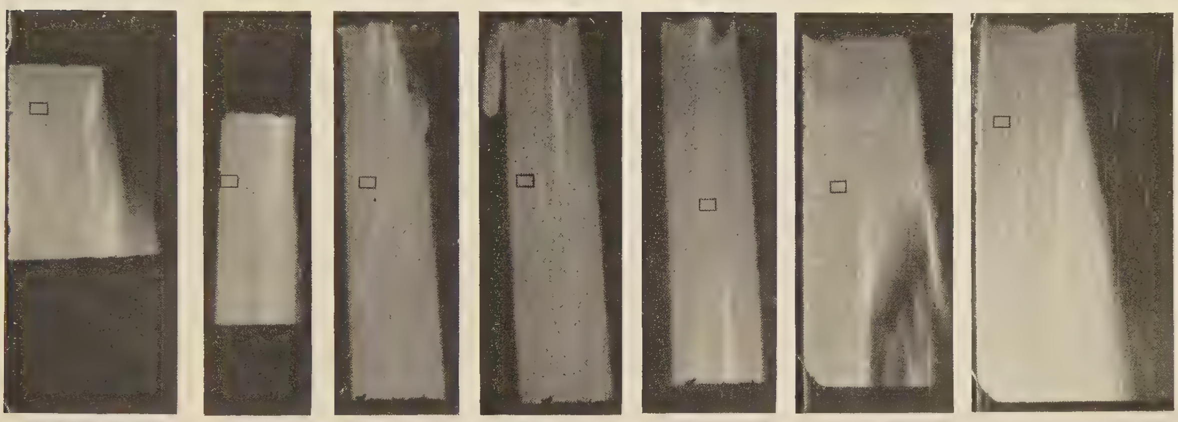


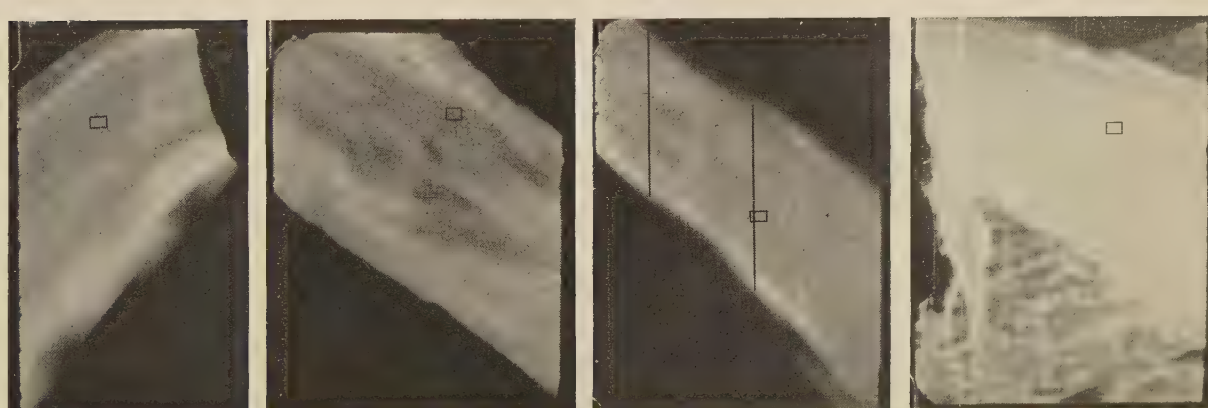
FIG. 22—Photograph representing casting stream seen through the optical pyrometer



(a) (b) (c) (d) (e) (f) (g)

(*a*) Reel 18, shot 3 (*see* Fig. 2)
(*b*) Reel 34, shot 9 (*see* Fig. 4)
(*c*) Reel 20, shot 1 (*see* Fig. 5)
(*d*) Reel 20, shot 5 (*see* Fig. 6)
(*e*) Reel 20, shot 10 (*see* Fig. 7)
(*f*) Reel 22, shot 11 (*see* Fig. 8)
(*g*) Reel 23, shot 7 (*see* Fig. 9)

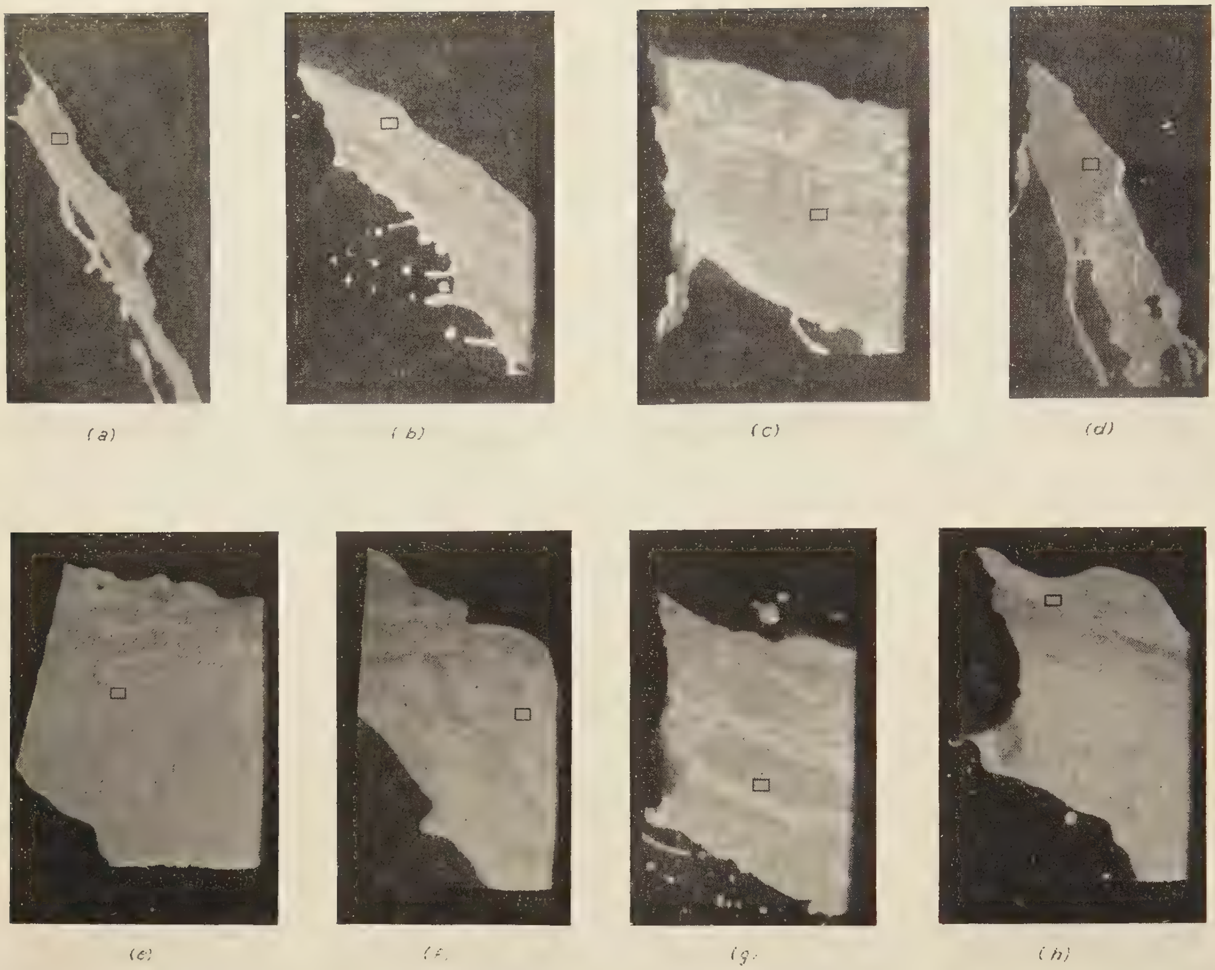
FIG. 23—Casting streams ; 20 millisecond exposures



(a) (b) (c) (d)

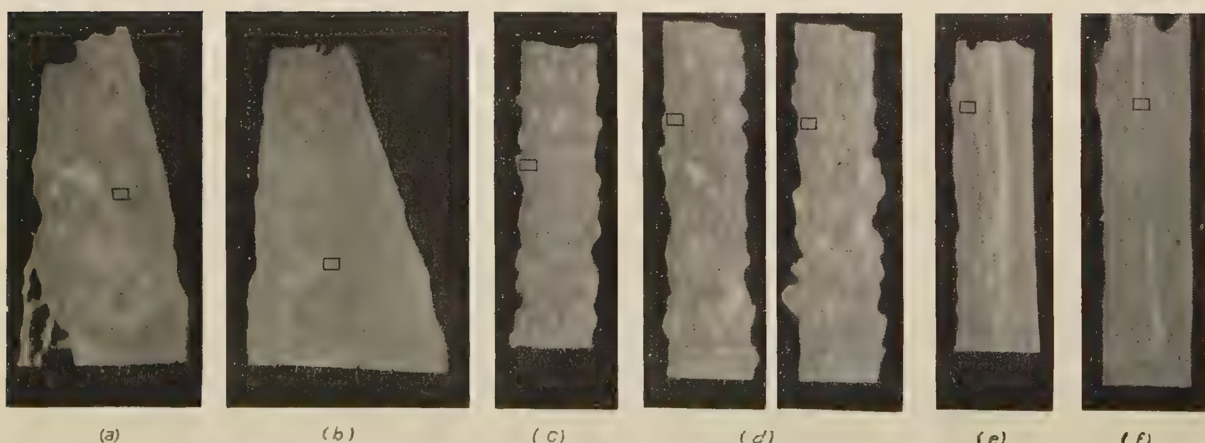
(*a*) Reel 18, shot 5 (*see* Fig. 11)
(*b*) Reel 34, shot 8 (*see* Fig. 13)
(*c*) Reel 19, shot 3 (*see* Fig. 14)
(*d*) Reel 23, shot 5 (*see* Fig. 20)

FIG. 24—Tapping streams ; 20 millisecond exposures



(a) Reel 40, shot 1 (*see* Fig. 29)
(b) Reel 40, shot 3 (*see* Fig. 30)
(c) Reel 40, shot 9 (*see* Fig. 31)
(d) Reel 37, shot 1 (*see* Fig. 35)
(e) Reel 29, shot 3 (*see* Fig. 28)
(f) Reel 30, shot 1 (*see* Fig. 34)
(g) Reel 30, shot 8 (*see* Fig. 36)
(h) Reel 30, shot 9 (*see* Fig. 37)

FIG. 25—Tapping streams ; 1·3 millisecond exposures



(a) Reel 30, shot 3 (*see* Fig. 39)
(b) Reel 30, shot 4 (*see* Fig. 40)
(c) Reel 30, shot 11 (*see* Fig. 41)
(d) Reel 30, shot 12 (*see* Fig. 42)
(e) Reel 30, shot 13 (*see* Fig. 43)
(f) Reel 30, shot 4 (*see* Fig. 40)

FIG. 26—Casting streams ; 1·3 millisecond exposures

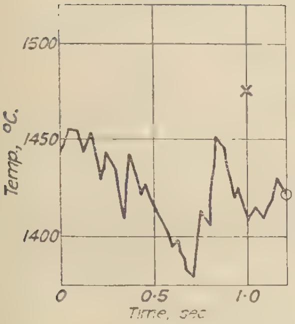


FIG. 27—Reel 29, shot 1. Same heat as Fig. 28

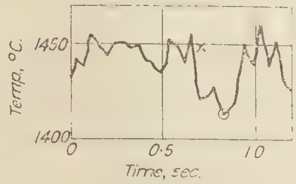


FIG. 32—Reel 37, shot 4. Same heat as Fig. 33

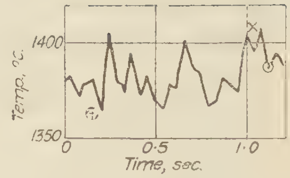


FIG. 35—Reel 37, shot 1 (*see* Fig. 25 (*d*))

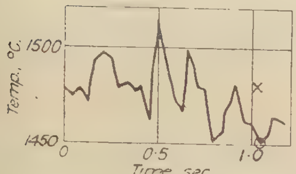


FIG. 28—Reel 29, shot 3 (*see* Fig. 25 (*e*)). Same heat as Fig. 27

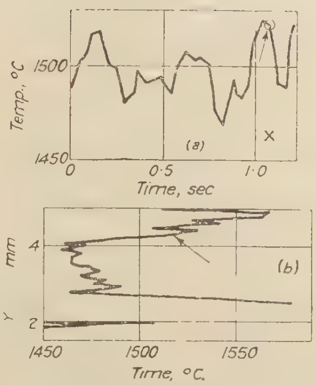


FIG. 33—Reel 37, shot 5. Same heat as Fig. 32

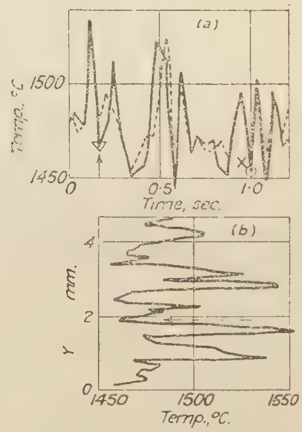


FIG. 36—Reel 30, shot 8 (*see* Fig. 25 (*g*)). Same heat as Fig. 37

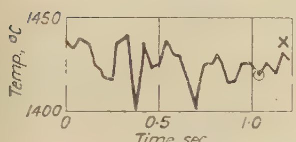


FIG. 29—Reel 40, shot 1 (*see* Fig. 25 (*a*)). Same heat as Figs. 30 and 31

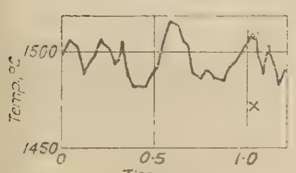


FIG. 30—Reel 40, shot 3 (*see* Fig. 25 (*b*)). Same heat as Figs. 29 and 31.

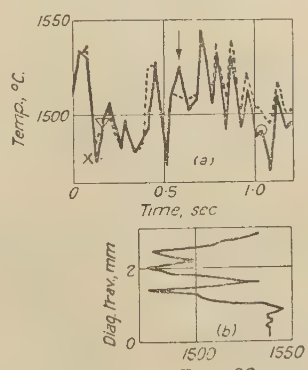


FIG. 34—Reel 30, shot 1 (*see* Fig. 25 (*f*))

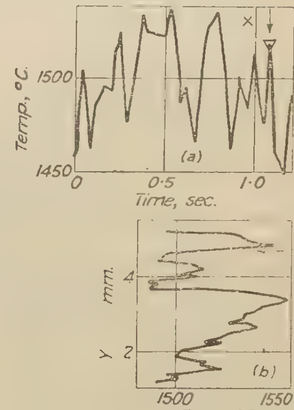


FIG. 37—Reel 30, shot 9 (*see* Fig. 25 (*h*)). Same heat as Fig. 36

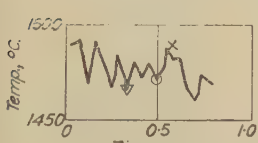


FIG. 31—Reel 40, shot 9 (*see* Fig. 25 (*c*)). Same heat as Figs. 29 and 30

Figs. 27–37—Tapping streams, 1·3 milliseconds exposure

(L = ladle, M = mould, R = runner box; X = optical reading, O = selected frame, and ∇ = frame enlarged)

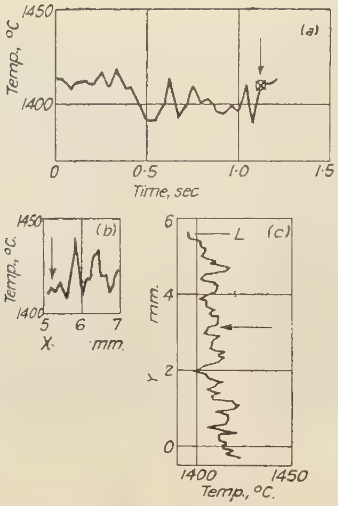


FIG. 38—Reel 29, shot 9

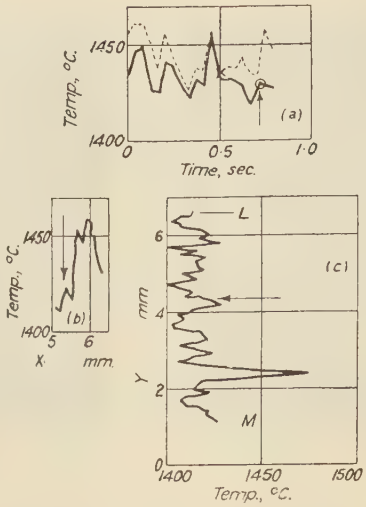


FIG. 41—Reel 30 shot 11 (*see* Fig. 26 (*c*)). Same heat as Figs. 42 and 43

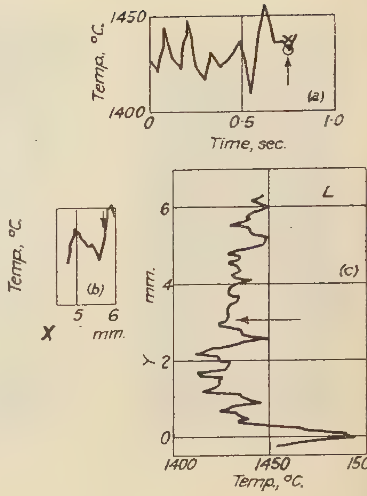


FIG. 44—Reel 37, shot 8. Same heat as Fig. 45

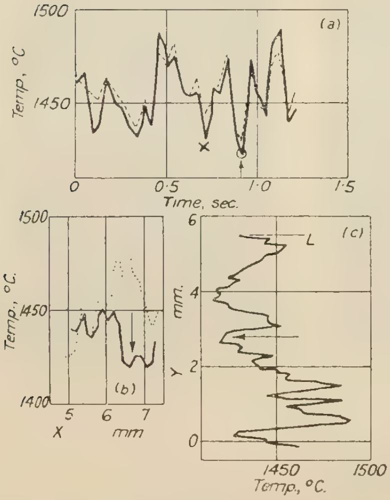


FIG. 39—Reel 30, shot 3 (*see* Fig. 26(*a*)). Same heat as Fig. 40

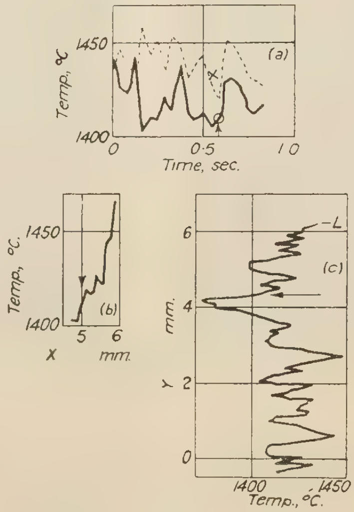


FIG. 42—Reel 30, shot 12 (*see* Fig. 26 (*d*)). Same heat as Figs. 41 and 43

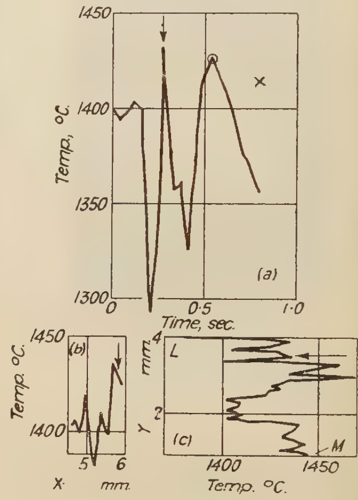


FIG. 45—Reel 37, shot 14. Same heat as Fig. 44

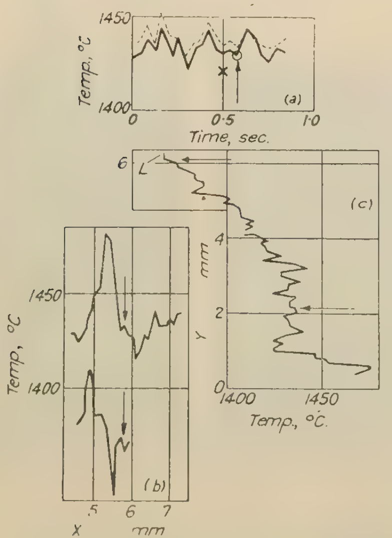


FIG. 40—Reel 30, shot 4 (*see* Fig. 26 (*b*)). Same heat as Fig. 39

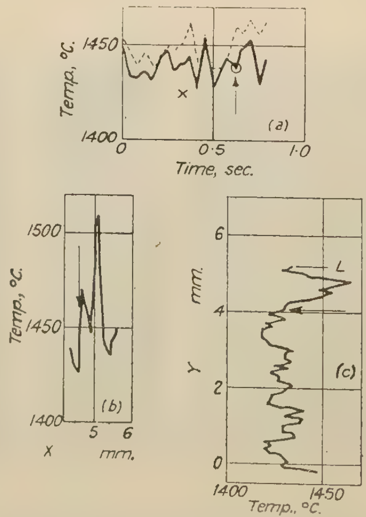


FIG. 43—Reel 30, shot 13 (*see* Fig. 26 (*e*)). Same heat as Figs. 41 and 42

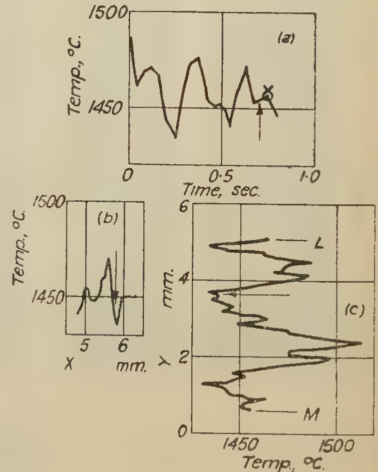


FIG. 46—Reel 42, shot 4

Figs. 38–46—Casting streams, 1·3 milliseconds exposure

L = ladle, *M* = mould, *R* = runner box; *X* = optical reading, *O* = selected frame, and ∇ = frame enlarged)

Table V—*Conditions under which Observations Were Made*

Tapping streams, photographed with 1·3 millisecond exposures

Run. Reel.	Run. Shot.	Figure Nos.	Steel. Composition.	Steel. Furnace.	Immersion Thermocouple Reading, °C.	Bath Additions.	Time of Shot.	Observer's Remarks.
29	1	27	0·75% Cr	15-ton basic arc	1595	None	Start of tapping, $1\frac{1}{2}$ min. after thermocouple reading.	...
29	3	28, 25 (*e*)	,,	,,	,,	,,	$2\frac{3}{4}$ min. after thermocouple reading.	...
40	1	29, 25 (*a*)	0·10–0·12% C (for tube)	80-ton basic open-hearth	1608	,,	1 min. after thermocouple reading.	...
40	3	30, 25 (*b*)	,,	,,	,,	,,	2 min. after thermocouple reading.	...
40	9	31, 25 (*c*)	,,	,,	,,	,,	8 min. after thermocouple reading.	...
37	4	32	0·08–0·12% C	,,	1614	,,	1 min. from start.	
37	5	33	,,	,,	,,	,,	$1\frac{1}{2}$ min. from start.	...
30	1	34, 25 (*f*)	1·0%, Ni, 1·5% Cr	15-ton basic open-hearth	1620	...	Start of tapping, 1 min. after thermocouple reading.	...
37	1	35, 25 (*d*)	0·61–0·65%C	80-ton basic open-hearth	1576	None	Start of tapping.	...
30	8	36, 25 (*g*)	0·75% C	30-ton acid open-hearth	...	...	Start of tapping.	...
30	9	37, 25 (*h*)	,,	,,	...	...	End of tapping.	Slag; metal streak at top.

Table VI—*Conditions under which Observations Were Made*

Casting streams, photographed with 1·3 millisecond exposures

Run Reel.	Run Shot.	Figure Nos.	Steel. Composition.	Steel. Furnace.	Casting Method.	Time of Shot.	Observer's Remarks.
29	9	38	0·75% Cr	15-ton basic arc	Upcast, $1\frac{3}{4}$-in. nozzle.	3 min. from start (end of 2nd of 3 plates).	Slaggy stream.
30	3	39, 26 (*a*)	1% Ni, 1·5% Cr	15-ton basic arc	Runner box, $1\frac{3}{4}$-in. nozzle.	$\frac{3}{4}$ min. from start (end of 1st ingot).	...
30	4	40, 26 (*b*)	,,	,,	,,	$4\frac{1}{2}$ min. from start (end of 2nd ingot).	...
30	11	41, 26 (*c*)	0·75% C	30-ton acid open-hearth	Upcast, 2-in. nozzle.	$\frac{3}{4}$ min. from start (end of 1st plate).	Slaggy.
30	12	42, (26) *d*	,,	,,	,,	$4\frac{3}{4}$ min. from start (3rd plate).	...
30	13	43, 26 (*e*)	,,	,,	,,	$10\frac{1}{2}$ min. from start (5th plate).	Not as much slag as previously.
30	14	26 (*f*)	,,	,,	,,	$18\frac{1}{2}$ min. from start (7th plate).	Fairly clear.
37	8	44	0·08–0·12% C	80-ton basic open-hearth	Upcast, $1\frac{3}{4}$-in. nozzle.	End of 1st plate.	...
37	14	45	,,	,,	,,	End of 4th plate.	...
42	4	46	0·10–0·12% C (for tube)	80-ton basic open-hearth	,,	End of 1st plate.	

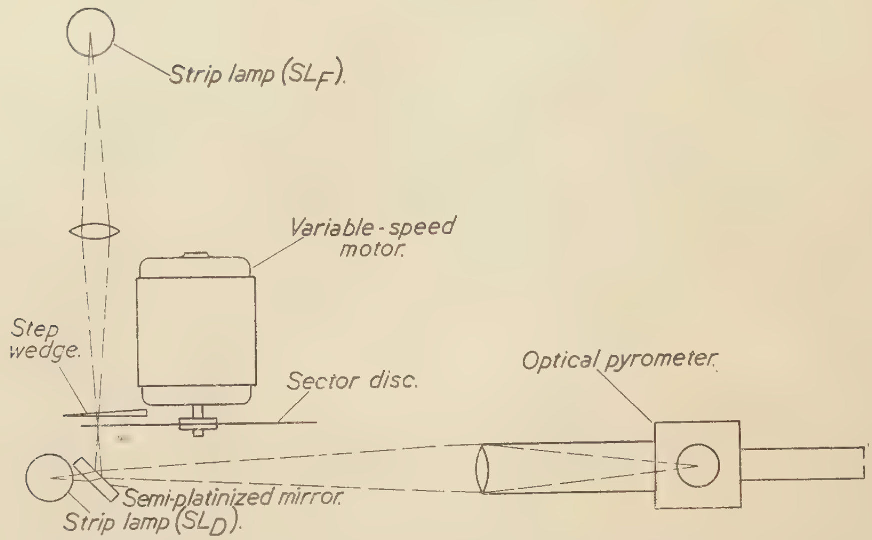


FIG. 47—Apparatus for examining a flickering field with an optical pyrometer

10° higher. Two extra observers who checked this observation also obtained the abnormally high value. The results of an additional experiment using a sector of 25% transmission are also plotted in Fig. 48 and show similar characteristics.

In these experiments the observers attempted to set the pyrometer filament to the mean brightness of the field at those frequencies at which flicker was visible. Some similar experiments have been made by Luckiesh[3] using a field which fluctuated between a known brightness and zero. In his work, the attempt was made to set the photometer to (*a*), the maximum and (*b*), the

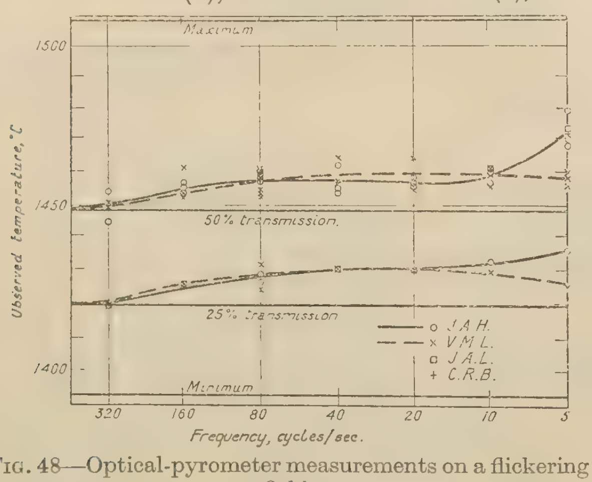


FIG. 48—Optical-pyrometer measurements on a flickering field

minimum brightness visible. His settings on maximum brightness ranged, as might be expected, from the true maximum at very low frequencies to half that value at high frequencies. He found, however, that it was impossible to make settings on the minimum visible brightness, because the eye was too much affected by the intervening bright periods, a result which seems consistent with the present experiments in that it shows that the eye tends to be unduly influenced by the periods of high brightness.

The effect of non-uniformity of brightness over the field of view was examined with the aid of the same apparatus. For this purpose, the sector disc was removed and a series of small opaque spots (produced photographically on a high-contrast plate) was substituted. In this way, a small circular area of brightness corresponding to SL_D was seen surrounded by an area of brightness corresponding to $SL_D + SL_F$. The temperature difference between the two areas was less than in the previous experiment on account of absorption by the clear portion of the photographic plate bearing the opaque spots. Though the transmission of these spots was probably negligible, the precaution was taken of measuring the brightness of SL_D while SL_F was obscured by a large dense area on the same photographic plate. The results are plotted in Fig. 49.

Since the width of the image of either of the

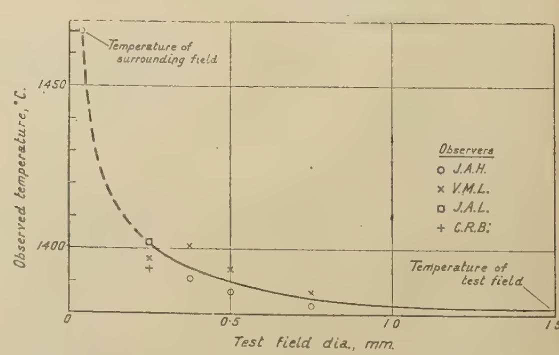


FIG. 49—Optical-pyrometer measurements on a non-uniform field

strip-lamp filaments, expressed in millimetres measured at the pyrometer filament, was only 0·75 mm. it was not possible to provide a bright surround to a spot any greater in diameter than this. The observations in Fig. 49 therefore cover a range of fields from this diameter down to 0·25 mm. (approximately equal to the $0 \cdot 3 \times 0 \cdot 2$ mm. area used for the normal film analysis). The temperature of the test field was measured with SL_F completely obscured, so that the curve can be extended to this value for an infinite field, while in the other direction, the pyrometer reading would correspond to the temperature of the surrounding field when the test field became so small as to be obscured completely by the pyrometer filament. Clearly, the interpolated portion of the curve shown by a broken line cannot be defined at all accurately.

In this experiment the same observers were employed as before, and all agreed in reading from 15° to 20° too high when a 0·25-mm. field at about 1400° C. was surrounded by a region at a temperature some 80° higher.

Taking the results of the two experiments into consideration it appears likely that an observer attempting to read the darker parts (*i.e.*, the clean steel) in a source such as a tapping stream would be likely to read some 10° higher than the mean brightness temperature of what was passing across his field of view.

V—Discussion of Results

As has been mentioned in the introduction to this paper, steel streams very frequently exhibit variations in brightness, and therefore in apparent temperature, which are clearly visible to the eye. This is invariably so in tapping streams, while in casting streams the variations are less marked and sometimes none is visible. The short-exposure photographs of Figs. 25 and 26, however, show that these variations in brightness are more extensive than unaided vision would suggest. It is the aim of the user of an optical pyrometer to take a reading on a clean metal surface, so that by applying the correction appropriate to the emissivity of liquid steel, a measure of the true temperature may be obtained. Apart from the presence of smoke, the darkest part of the stream will be the clean metal, so the observer will endeavour to avoid any specially bright regions which are visible. Small bright patches, such as those of Fig. 26 (*d*), which, by reason of their rapid passage across the field of vision, are invisible, will none the less serve to raise the apparent brightness and lead to a high reading.

Enhanced brightness of the surface may be caused by the presence of material having a higher emissivity than steel, such as slag or refractory material from nozzle erosion. It may also be the effect of a fold in the surface of the stream, which creates a partial black-body enclosure. This latter effect is well illustrated in Fig. 25 (*d*), which shows the tapping stream from an open-hearth furnace at an early stage when the tap-hole had been imperfectly opened. The clear zone at the mouth of the launder persists throughout the shot, and at no time does any bright patch cross it. Yet the stream is invariably brighter in the lower part of the picture, and it will be seen that the effect begins just where the stream is beginning to break up. This is a clear indication that the enhanced brightness is caused by the configuration of the surface and not by foreign matter.

If we consider a surface of emissivity E at the temperature at which the brightness of a black body would be B, then the brightness of the emitting surface will be EB. Its reflectivity will be $(1 - E)$, and if the point at which we are looking happens to reflect another part of the same surface which is also of brightness EB, then its total brightness will become $EB + (1 - E)EB$. If another reflection is caught, then the brightness will be increased by a further $(1 - E)^2\ EB$. If we assume an emissivity of 0·4 for a clean steel surface, then one reflection will increase this to 0·64, while a second will put it up to 0·78. Using a wave-length of $0 \cdot 65\mu$, these two values would increase an apparent (brightness) temperature of 1400° C. to 1465° and 1490° C. respectively. Since the temperatures recorded on the time/temperature graphs of Figs. 2–20 and 27–46 relate to a fixed point in space, it is clear that variations in brightness of this order over the surface of a moving stream could be responsible for the fluctuations, sometimes amounting to about 80° C., which have been recorded.

The value of the emissivity of slag is very nearly the same as that for clean steel reinforced by one reflection. A slag surface reinforced by one reflection, however, would yield an emissivity value of 0·87.

The right-hand photograph of Fig. 26 (*d*) has been studied in detail in the light of the above discussion. The left-hand photograph is the selected frame but the other (which was, in fact, the next frame following) was picked as more suitable for the present purpose. It is clear that an irregular surface such as is shown by the profile of this stream could readily create partial black-body conditions in the hollows. In order to investigate the matter geometrically, an enlarged tracing was prepared, and is reproduced in Fig. 50. The X and Y co-ordinates are marked in

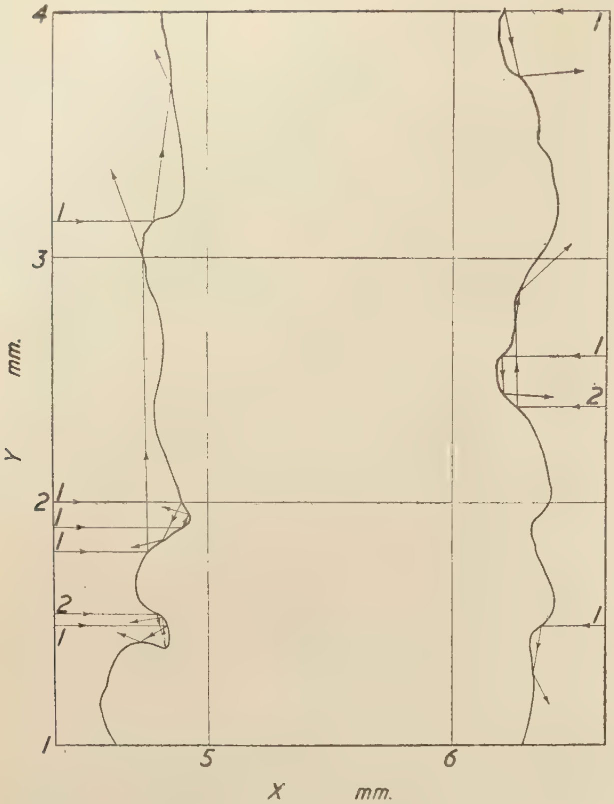


FIG. 50—Profile of casting stream. Reel 30, shot 12 (Fig. 26 (*d*), right) showing reflections

millimetres. Rays were traced approximately normal to the axis of the stream and at intervals corresponding to 0·1 mm. on the film. Regarding these rays as being the line of vision of the observer, and assuming reflection to be specular, those which picked up one or more reflections have been reproduced in the diagram. Only two rays pick up more than one reflection, and in order to find one of these (located at $Y = 1{\cdot}55$) it was necessary to depart from the regular 0·1-mm. spacing of the rays. The form of the reflections shown at $Y = 2{\cdot}4$ on the right-hand side indicates that with almost grazing incidence multiple reflections could occur, but clearly a region over which this could happen would be likely to be very small in area. With specular reflection therefore, more than one reflection would seem to be unusual.

It will be realized that this analysis is only two-dimensional, but the chances of a second reflection in a deep cavity are just about as great in any one plane as another, so that a change into another plane on reflection is not likely to affect the result. With a shallow depression, such as the one which causes a second reflection on the right of Fig. 50, the chances of a second reflection will be somewhat less in any plane other than that of the diagram on account of the sharp convex

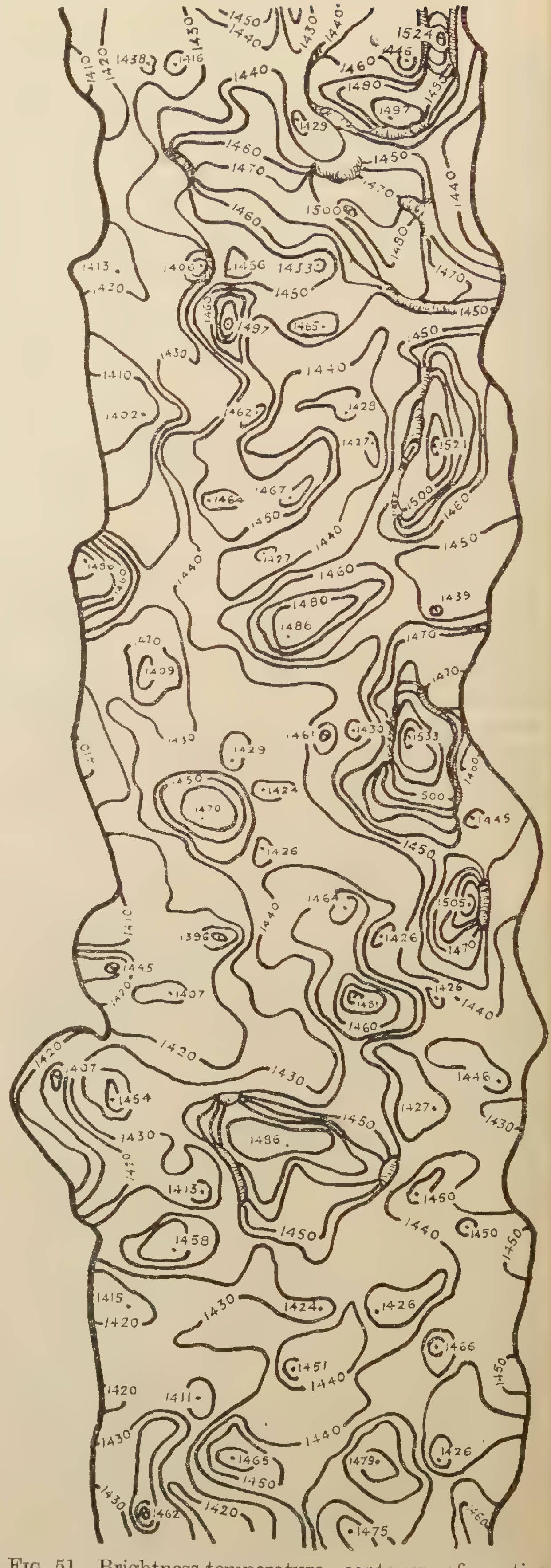


FIG. 51—Brightness temperature contours of casting stream. Reel 30, shot 12 (Fig. 26 (*d*) right)

curvature of the surface of the stream in a horizontal plane.

It must also be emphasized that the analysis is based on the assumption that the surface is specular and fairly smooth. Clearly, a very fine ripple could increase materially the chances of reflection. Further, no account has been taken of an actual rise in temperature of the surface in a hollow through the absorption of radiation from neighbouring parts of the surface.

Referring to Fig. 26 (*d*), it seemed probable that the dappled appearance of the stream was caused by the presence of hollows similar to those shown in the profile, but facing the camera. A contour map of the brightness temperatures recorded by this frame of the film is given in Fig. 51. Two characteristics of this map may be noted. First, the heights of the "peaks" above the surrounding "plain" vary between 40° and 80° C., the distribution being fairly regular over this range. Second, the contours are very closely packed round the peaks (there are, in fact, numerous "cliffs"), an effect which is consistent with an abrupt transition between a completely exposed surface and one of which the brightness has been reinforced by a single reflection.

The observations from which the map was drawn have been analysed in another way. The frequency of occurrence of any temperature, independent of its position in space, has been plotted in Fig. 52. For this purpose the density

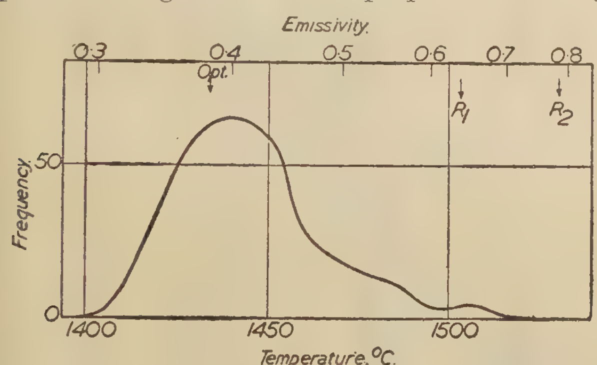


FIG. 52—Frequency curve of temperature distribution. Reel 30, shot 12 (Fig. 26 (*d*), right)

values have been rounded to the nearest 0·01 (about 4° C.). It will be seen from the vertical traverse in Fig. 42 that there is no systematic brightness gradient along the length of the stream, so the main peak of the frequency curve, centred on 1440° C., probably represents with fair accuracy the brightness of the clean metal surface, while the asymmetry of the curve as a whole is accounted for by the bright patches. A scale of emissivities (based on the assumption of a value of 0·4 for the open metal surface) is shown in Fig. 52, while the values of the optical-pyrometer reading and the brightnesses for one and two reflections (R_1 and R_2), deduced from the brightness of the main peak, are also shown.

If the scanning spot were negligibly small compared with the bright patches, and these were all of the same brightness, there would be two sharp peaks in the frequency curve, one representing the brightness of the dark background and the other that of the patches. With a finite scanning spot, however, some of the observations which fall

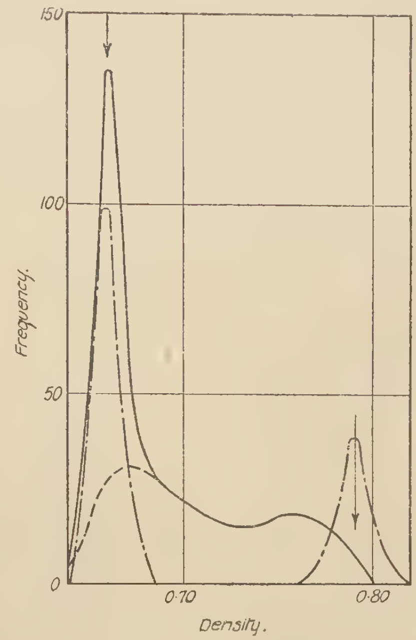


FIG. 53—Frequency curve of density distribution of test field (narrow bright band)

mainly on the background will be influenced by a bright patch, while a considerable proportion of those which fall mainly on bright patches will be partly on the background. We should thus expect the background peak to be displaced slightly towards a higher temperature, while the peak representing the bright patches would be low to a somewhat greater extent. In Fig. 52 there is some evidence of a peak at about the calculated brightness for R_1, while the space between this and the main peak is completely filled in, with an appreciable shoulder on the curve corresponding to $E = 0 \cdot 55$.

In order to assist in the interpretation of curves of this type a special test object was set up and photographed. For this purpose the opal and mask referred to in section (ii) of the Appendix were used. A time exposure was made on the illuminated opal, and then a second exposure 0·6 times as long as the first was made with the mask in place. In this way, an image of an even brightness was recorded, and this was crossed

by a broad and a narrow band, each 1·6 times as bright as the background. The width of the bands was adjusted by varying the distance between the camera and the test object. Both intensities appearing in the field could be measured by means of observations on the background and on the broad bright band. These two measurements are recorded in the two frequency curves shown by chain lines in Fig. 53, and it will be seen that the two densities are quite accurately identified as 0·790 and 0·660. The width of the narrow band on this film was 0·113 mm., and the frequency curves which appear as continuous and as broken lines in Fig. 53 relate to a large number of short traverses across this band. Considerable care was taken to ensure that the position of the start of

Fig. 54—Frequency curve of density distribution of test field (broad bright band)

each traverse was determined in a random manner, so that in successive traverses the way in which the images of the scanning spot were located across the band was dependent on pure chance. The continuous line in the lower curve of Fig. 53 records traverses 0·5 mm. long (*i.e.*, about 4 times the width of the bright band) while the broken line shows the effect of shortening the traverses to 0·3 mm. The arrows indicate the true brightnesses of the two zones as given by the chain curves. As might be expected with a band of about the same width as the scanning spot, very few of the observations on the band record the true brightness, and the peak in the curve is displaced to a density about 0·03 (say 12° C.) lower. With the broken-line curve, in which the traverses averaged only 0·09 mm. on either side of the bright line, the peak representing the background has been displaced to a density about 0·01 too high owing to the fact that a large proportion of the observations fell partly on the bright band. Increasing the length of the traverses, and thus the width of background examined, leads to a peak in almost exact agreement with the true brightness value.

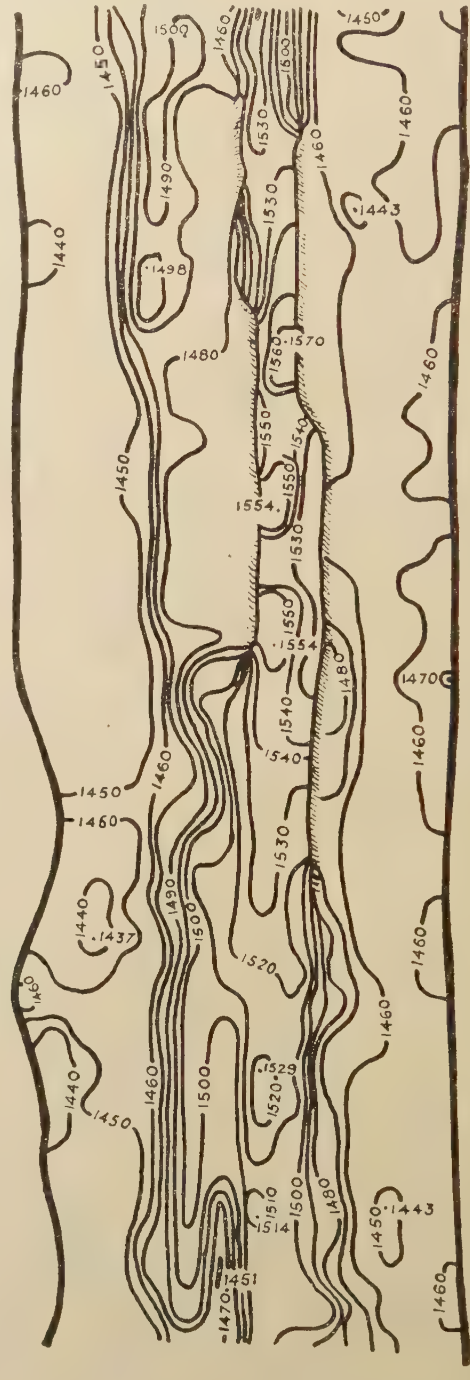


Fig. 55—Brightness temperature contours of casting stream. Reel 30, shot 13 (Fig. 26 (*e*))

Figure 54 shows a similar experiment with the width of the bright band increased to 0·230 mm. and the lengths of the traverses to 0·5 and 0·9 mm., preserving approximately the same relationship to the width of the band as in the other experiment. Here, the brightness of the band is accurately recorded, but the broken line shows that the displacement of the background peak is still present when the short traverses are used.

These experiments suggest two criteria in examining curves of this type. First, if the peak representing clean metal is two or three times as high as the subsidiary peak, it probably records

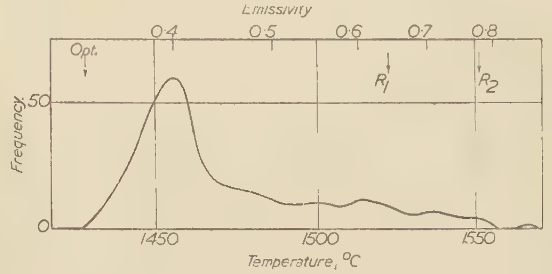


FIG. 56—Frequency curve of temperature distribution. Reel 30, shot 13 (Fig. 26 (*e*))

the true brightness temperature. Second, a reliable value cannot be obtained for the bright patches by this means unless most of them are at least twice as wide as the scanning spot. A reduction

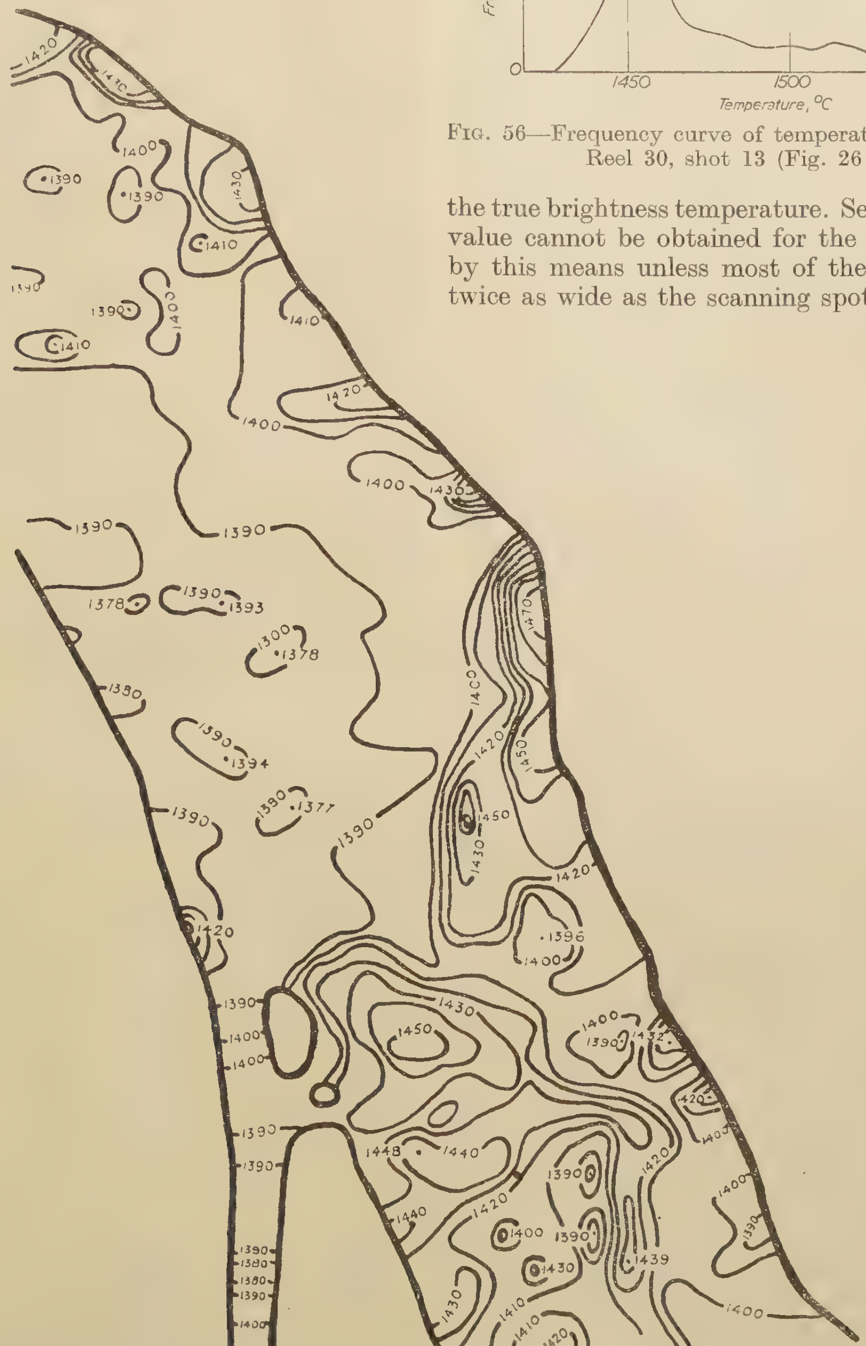


FIG. 57—Brightness temperature contours of tapping stream. Reel 37, shot 1 (Fig. 25 (*d*))

in size of the scanning spot was tried, but this led to markedly inferior resolution, presumably owing to the intrusion of the graininess of the emulsion. Improvement, therefore, could only be obtained by increasing the size of the image unless a much finer-grained emulsion were available.

Returning, then, to Fig. 52, the value for the main peak probably represents the brightness of the open steel surface fairly closely, but, since Fig. 26 (*d*) (right) shows that few of the bright patches are as much as 0·2 mm. across, the curve cannot give a very reliable value for their brightness. Comparison with the broken-line curve of Fig. 53, which is not dissimilar in form, suggests that an apparent temperature of 1510° C. would not be far out, and this corresponds moderately well with the value calculated for one reflection.

Figures 55 and 56 show a contour map and frequency curve for the frame of reel 30, shot 13, reproduced in Fig. 26 (*e*). This shot is of a later stage in the same cast as that which has just been considered and the emissivity scale has again been drawn by assuming a value of 0·4 for clean metal. The stream has now become more regular in character, but there is a pronounced bright streak which was almost certainly caused by the products of nozzle erosion. The contour map records the streak as being much brighter at the upper end, a fact which suggests that in this region we may have the combined effect of refractory material and deformation of the stream caused by nozzle wear, the distortion being more or less smoothed out in the lower part of the stream. In view of the poor resolution, however, it would be unwise to place much reliance on this deduction. The frequency curve is quite different in character from that for the " dappled " stream, much higher brightnesses being reached but with little evidence of any subsidiary peaks in the frequency curve. It is perhaps worth noting that the upper limit of the frequency curve just reaches an emissivity value of 0·87, the value calculated for a slag surface reinforced by one reflection, thus giving some confirmation of the theory of the character of the bright streak suggested above.

The tapping stream shown in Fig. 25 (*d*) has been analysed in the same way, Figs. 57 and 58 being the contour map and frequency curve respectively. The contour map shows the whole of the upper region (except for one or two small patches on the edge) to be uniform in brightness to within ten or twenty degrees, while the frequency curve is not very different in character from that of Fig. 52. Again, by comparison with Fig. 53, the upper limit of the main part of the curve is consistent with the R_1 value. The small isolated peak at 1480° C. corresponds to the bright " knee " which is clearly visible in Fig. 25 (*d*). It seems most likely that this patch was caused by a small piece of refractory floating on the stream, possibly combined with deformation of the surface. Since it was evident that the temperature of the thin stream in this shot was considerably below that recorded by the immersion thermocouple just before the furnace was tapped, the emissivity scale has again been drawn on the assumption of a value of 0·4 for clean metal, but in Fig. 59, which corresponds to Fig. 25 (*c*), the emissivity values have been based on the assumption that the true temperature was equal to that which had just been measured in the furnace. This is probably not very far from the truth, as the 80-ton bath would not change rapidly in temperature,

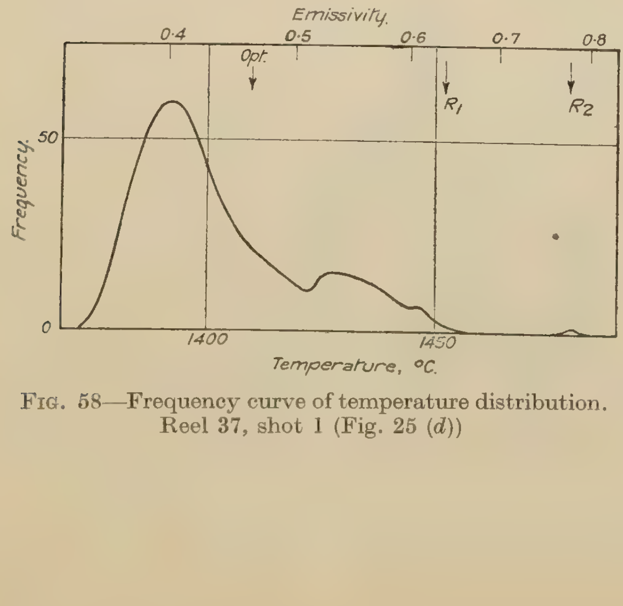


FIG. 58—Frequency curve of temperature distribution. Reel 37, shot 1 (Fig. 25 (*d*))

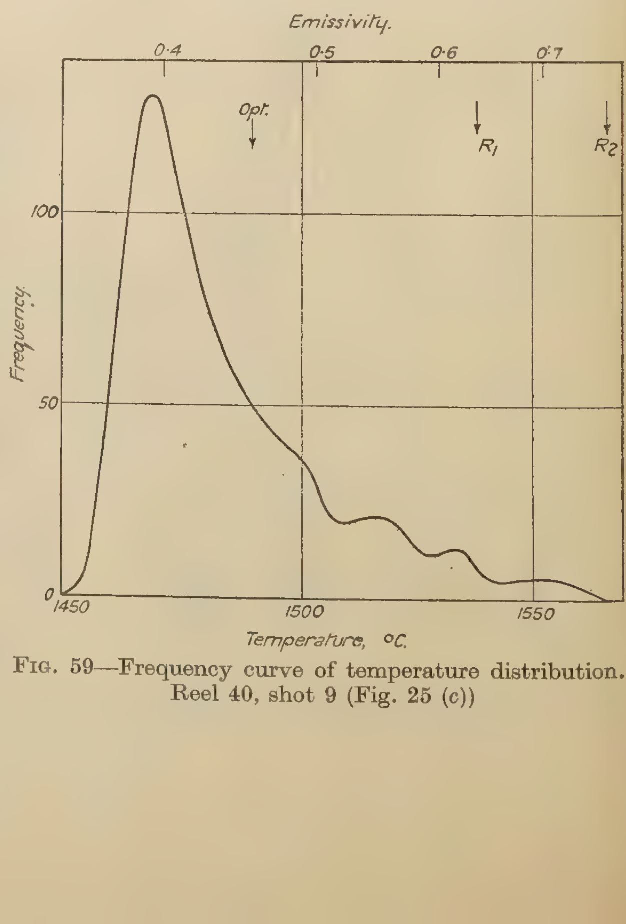


FIG. 59—Frequency curve of temperature distribution. Reel 40, shot 9 (Fig. 25 (*c*))

the stream was of generous proportions and the launder had had time to be thoroughly warmed. In this instance the proportion of clear metal is evidently greater, and the value given by the main peak is almost certainly reliable, while the upwards extension of the curve shows the same general characteristics as Fig. 52 with the addition of a small peak just above 1550° C. The readings which give rise to this peak are those which occurred in the broad bright patch in the bottom left-hand corner of the photograph. This may be of the same brightness as the narrow streaks which have led to the peak at 1535° C. but, as the observations were taken in a large bright area, they will have been recorded at their correct value, while those in other regions are probably too low on account of the poor resolution. On the other hand, as the brightness of this patch is well above R_1, there may have been some surface contamination.

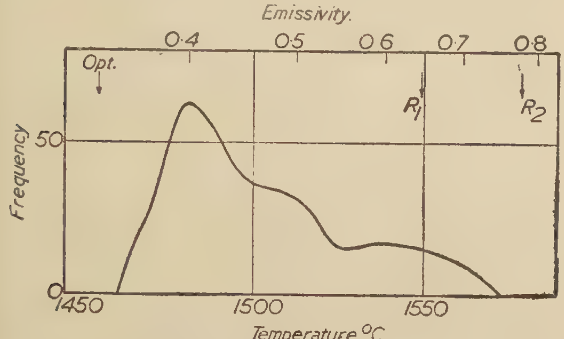


FIG. 60—Frequency curve of temperature distribution. Reel 30, shot 8 (Fig. 25 (*g*))

Figure 60 relates to the photograph of Fig. 25 (*g*), and the results are again akin to those given by Fig. 52, namely, a peak consistent with the value calculated for one reflection and with an intermediate shoulder on the curve.

Figure 25 (*f*) shows an early stage in the tapping of an electric furnace, when there was obviously much slag in the stream. The frequency analysis of this photograph is given in Fig. 61. Here the

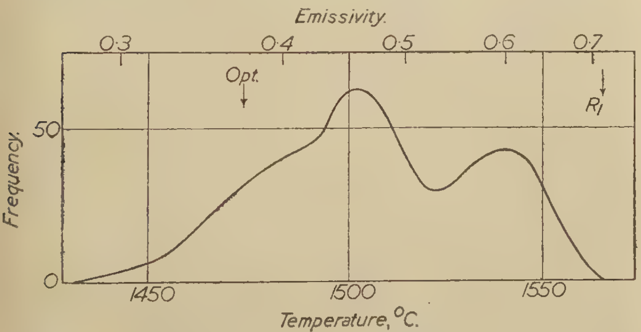


FIG. 61—Frequency curve of temperature distribution. Reel 30, shot 1 (Fig. 25 (*f*))

curve is of a very different character and can obviously give no reliable value for the metal temperature. The emissivity scale is based on the immersion thermocouple reading in the furnace 1 min. before the photograph was taken, and suggests that the shoulder on the left of the main peak is perhaps caused by small areas of clean metal, and this is not inconsistent with the optical pyrometer reading. Clearly, however, conditions such as this are quite unfavourable to optical-pyrometer observation, and reference to Fig. 34 makes it seem even more remarkable that the observer should have been able to pick out minima which are rare on both the time/temperature curve and on the traverse of a single picture. This traverse could not be made through the selected spot if it were to be approximately at right-angles to the direction of flow. Consequently, there is no point in common between the traverse and the time/temperature curve and hence no arrow appears on the traverse. In none of these frequency curves has any attempt been made to use observations on more than one frame. Since the unsteadiness in the running of the camera is such as may introduce differences of the order of 5° C. between successive frames, it was thought that any extension of the work in this direction was best deferred until this error had been eliminated (*see* section VII).

Reference has already been made to one possible cause of a difference between the reading of an optical pyrometer and that of the mean temperature recorded by the film. The observed discrepancy is, in many instances, considerably greater than could be accounted for by this means, but the reason is usually apparent from a study of the traverses of the streams which accompany the time/temperature curves. Referring to Figs. 2 to 10 (casting streams, 20 millisecond exposure), it will be seen that in Figs. 2 and 9, where the difference is large, there is a very considerable brightness-temperature gradient from top to bottom of the stream. This is of the order of 20° C. per inch of stream (per millimetre on the film), so that a discrepancy of 40° or 50° C. is hardly a matter for surprise. This gradient has often been observed (if not measured) and can probably be attributed to a reflection (" flash ") from the metal in the mould.* The effect can, of course, be complicated by smoke, and in Fig. 6 a reversed gradient (presumably caused by smoke rising from the mould) is shown. Figures 8 and 9,

* An alternative suggestion is that the gradient is caused by progressive oxidation of the metal, thus giving a higher emissivity at the lower end of the stream. If this were the true reason, however, one might reasonably expect the phenomenon to occur more frequently.

however, represent a common form of curve, the brightness being enhanced by reflection at the bottom and reduced by smoke hanging under the ladle at the top. The observer's remark, "*patch of slag*," in reference to the observation of Fig. 9, is evidently a misinterpretation of the cause of the local increase of brightness. Slag could not be present at such an early stage of the cast, and there was no evidence of nozzle erosion. The vertical traverse of the film makes the reason for the effect clear. In all, nine sets of observations were made on this cast, the optical pyrometer readings being 1431°, 1487°, 1437°, 1439°, 1433°, 1436°, 1423°, 1421°, and 1422° C. Any one of these readings except the second would have shown quite good agreement with the photographic record which was obtained for the second set. Evidently the disturbing reflection was only present for a short time, and no doubt the observation at 1487° C. would have been ignored by the observer in assessing the casting temperature.

In Figs. 38–46 (casting streams, 1·3 millisecond exposure) the agreement between the optical and photographic readings is, on the whole, closer than in the series with 20 millisecond exposures, but this better agreement is probably fortuitous. In these curves, as might be expected, there is a much greater difference in level between peaks and troughs, showing clearly that one can hardly expect any optical-pyrometer reading taken under normal conditions to give the brightness temperature which would be associated with a perfectly clean metal surface. The mean level of the curve is, in general, some 10° or 20° C. above that of the troughs, so that if these may be regarded as clean metal, we get an effective increase of emissivity of 10 or 20%. A very similar apparent increase is also obtained from most of the frequency curves if we measure the displacement of the centre of gravity of the curve from the position of the main peak.

The effect of smoke is well shown in Figs. 14, 18, and 45. In Fig. 14 the photographic reading of the temperature was very low compared with that of the optical pyrometer. Figure 24 (*c*) shows at once that smoke was covering the selected spot, so a second traverse was made in the clearer region near the mouth of the launder, the two traverses being indicated by vertical lines on Fig. 24 (*c*). This second traverse gives a value in agreement with the two peaks in the time/temperature curve, which evidently correspond to moments when the smoke had blown clear. Figure 18 shows a drop of about 80° C. persisting for about ¼ sec. This is probably due to the brief passage of some smoke which, on account of its short duration would not be likely to influence an observer with an optical pyrometer. The irregular time/temperature curve of Fig. 45 is caused by dense smoke from a tarred nozzle which was drawn down by the air currents around the rapidly moving stream. This is apparent when the film is projected. The smoke is so dense and confined to such well-defined streaks that it could hardly lead to an erroneous reading, though its presence would undoubtedly make the taking of a reading more troublesome.

Figure 19 shows two frames just after 0·5 sec. which are in turn about 25° C. above and below the general level of the curve. This is almost certainly the result of experimental error. The frames concerned were just at the bottom of the developing rack, where there is more risk of uneven development, while the shot is one of those recorded on reel 24, the whole of which gave rather erratic results in the calibration, probably through abnormal unsteadiness in the running of the camera (*see* Appendix, section (vi)).

Figures 39 and 40 include additional horizontal traverses. In Fig. 39 the brightness recorded by the frame next but one before the selected frame was so much higher than that given by the selected frame itself, that a traverse on the earlier frame was made in order to throw some light on the difference. This traverse is shown as a dotted line and reveals the fact that on the left-hand side of the stream the difference does not exist. The vertical traverse of Fig. 40 showed such a marked fall in brightness towards the nozzle that a second horizontal traverse was made at the top of the stream. The two horizontal traverses (their positions are indicated by the arrows on the vertical traverse) are notably similar in form, allowing for the splayed character of the stream (*see* Fig. 26 (*b*)). The curves relating to these two typical splayed streams show that they were among the worst for non-uniformity of brightness.

Normally, it will be seen that the positions of the arrows on the traverses and the time/temperature curves correspond closely in temperature. In Fig. 46, however, there is a marked discrepancy. An examination of the six observations on which the point on the time/temperature curve is based, however, shows that they have a considerable spread, and that one of them corresponds to a temperature of 1436° C., which is approximately the value shown on the traverses. Figure 13 shows a similar (though somewhat smaller) discrepancy and this can be explained in the same way.

When the observations recorded in Fig. 4 were made, the casting stream (of high-speed steel) was passed through a "temperature-ring,"[4] so that the true temperature could be measured by means of a thermocouple. The value found was 1503° C.

Using the optical pyrometer reading of 1394° C. we arrive at a value of 0·45 for the emissivity. The temperature level of the selected spot remained fairly constant at about 1370° C., giving an emissivity of 0·37 ; while the highest point on the horizontal traverse gives 0·55. These observations, however, were made with 20 millisecond exposures and so do not give a complete analysis of the brightness of the surface of the stream.

The broken curves giving the results of the exploration with a scanning spot of 0·6-mm. dia. show that with a field of this size the reading may be increased by as much as 30° C. but that the rise is normally of the order of 5° or 10° C. Though the evidence is rather too scanty to justify the drawing of any definite conclusion, it is perhaps significant that in Figs. 41, 42, and 43 the only run in which the optical pyrometer reading is higher than the photographic value is that of Fig. 42 which also shows the biggest discrepancy between the values given by the large and small scanning spots. If any reliance can be placed on this fact, it is at any rate in accord with the conclusion drawn from the second experiment described in section IV.

Attention may be drawn to the excellent agreement between the optical-pyrometer and photographic values in Fig. 10. This stream is shown to be perfectly regular apart from a slight reduction in brightness just below the ladle. On this occasion the stopper had jammed, and the flow was thus completely unrestricted. It was noted generally that in normal operation the stream was more regular towards the end of a cast, when the head in the ladle was reduced and the flow was no longer being restricted by stopper control. The series of photographs in Figs. 26 (*c–f*) show this progressive improvement clearly.

Reference to the results obtained on tapping streams shows similar effects in somewhat exaggerated form. In Fig. 11 the big difference between optical and photographic readings is associated with very high brightness gradients. In Fig. 20 it was thought that the high optical reading might be caused by reflection from the slag in the ladle (*see* Fig. 24 (*d*)), but the traverse of the stream, while showing increased brightness at the bottom, by no means accounts for the discrepancy. In the same way, the traverse on Fig. 16 fails to account for the high optical reading. The high photographic value in Fig. 33 is clearly explained by the traverse, which indicates that the coordinates of the selected spot were probably slightly in error. Fig. 36 shows that the optical observer has been very successful in picking out the minimum brightness of the stream. In the next shot, however (Fig. 37) he appears to have sighted on the slag, while his selected point for analysis has fallen more frequently on the small streak of metal which it just misses in Fig. 25 (*h*).

The graphs in Figs. 2–20 and Figs. 27–46 to which no special reference has been made were selected as making as representative a collection as possible from all the results which have been obtained, particularly from the point of view of giving a balanced picture of the differences which occurred between the values of the temperature obtained with the optical pyrometer and those with the cinematograph film. The differences between the optical-pyrometer readings and the average levels of the corresponding time/temperature curves obtained from the film are plotted in the two frequency curves of Fig. 62. All the

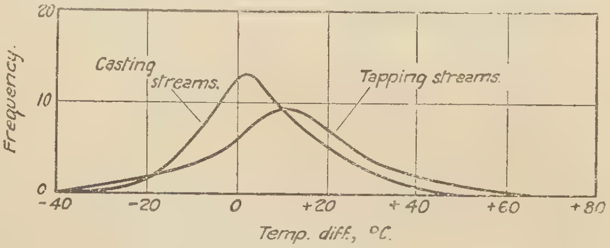


FIG. 62—Frequency curve of differences between optical and photographic observations

observations which have been reduced, whether plotted in this paper or not, have been included in this analysis. The average level of the curve was determined by visual inspection rather than by calculation, so that the effect of such events as the momentary passage of smoke could be ignored.

The improved consistency obtained with optical-pyrometer observations on casting streams as compared with those taken on tapping streams is shown by the difference in sharpness between the peaks of the two curves. Further, while the peak of the casting-stream curve shows almost exact agreement with the photographically determined value, that for tapping streams is some 10° C. higher. This difference is quite consistent with the results of the experiments with flickering and non-uniform fields described in section IV.

Measurement of the areas of sections of the frequency curves of Fig. 62 leads to the results given in Table VII. These figures are purely

TABLE VII—*Statistical Data taken from Fig. 62*

Source.	Mean Difference (optical minus photographic).	Proportion of Observations in which Departure from Mean Difference Does Not Exceed		
		±10° C.	±20° C.	±30° C.
Casting streams	+ 2° C.	60%	85%	95%
Tapping streams	+11° C.	50%	75%	90%

arithmetical values obtained from the curves, and it is not intended to suggest that the difference values are reliable to the nearest degree. The difference between the two figures of 2° and 11° is, however, probably just significant.

VI—Conclusions

The present work has shown very clearly that the conditions under which optical-pyrometer readings have to be taken on liquid steel in the works are such that only a skilled and experienced observer can hope to get results of satisfactory accuracy. The observer should have a reasonable theoretical knowledge of the subject so that he will be the better able to select the right part of a stream for observation and to know when to reject an observation because conditions were unsatisfactory. He must also study carefully the local conditions in the shops in which he is to operate, so as to be able to avoid, as far as possible, any smoke which may be present. Smoke, however, to a good observer, is not such a serious source of error as bright patches in the stream, which, through rapid movement, may not be visible to the eye at all. One point which is worth noting is that, owing to its scattering properties, a veil of smoke between the observer and a non-uniform field will tend to minimize the contrast of the field. An inexperienced or careless observer might interpret this effect as meaning that conditions were good, but the intervening smoke will normally reveal itself to the careful observer by its movement.

Taking everything into consideration, it is remarkable what a high degree of precision can be attained by a first-rate observer. Table VII indicates that probably five out of six observations will be within a range of ± 20° C. on casting streams or about ± 25° C. on tapping streams. The observations on the latter, however, will probably run consistently about 10° C. higher, and it may be considered worth while to apply a correction of − 10° C. to all tapping stream observations to secure better consistency. Even so, the brightness temperatures recorded will all probably be somewhat higher than they would have been had they been taken on an ideally smooth steel surface free from slag or other similar contamination. It appears probable that deformation of the steel surface, leading to partial black-body enclosures, is a more likely source of error than surface contamination.

The use of a photo-electric pyrometer, or other instrument requiring a field of larger size than that needed for an optical pyrometer, is not likely to lead to serious error. There will be, in general, a tendency for such an instrument to read still higher than the optical pyrometer, but if the conditions are such as to cause the difference to be more than 5° or 10° C. they should be readily apparent to the observer.

VII—Further Programme of Work

In view of the encouraging nature of the preliminary work on the frequency-curve method for isolating the brightness of the clean steel area of a non-uniform field, it is proposed to use this technique for a series of observations to determine the emissivities of a range of steels. In order to do this, direct comparison of film, optical pyrometer, and thermocouple observations will be made, using the "temperature ring"[4] for the latter.

In the light of the experience gained in the present work, the photographic technique will be modified to reduce as far as possible the following sources of error (set out in Table II):

(i) *Variation in exposure time*—A synchronous electric motor will be fitted to the camera in place of the governed clockwork hitherto used. The frequency of the mains supply will be measured during each observation.

(ii) *Irregularity in illumination and development of individual frames*—All reflecting parts in the camera will, as far as possible, be blackened.

(iv) *Time interval between observation and calibration*—The strip lamp and control gear will be set up in Sheffield, so that the calibration exposures may be made immediately after each observation.

(vi) *Uncertainty in drawing calibration curve*—A more accurate view-finder will be fitted to the camera, thus making it practicable to fill the picture space more completely. Larger strip-lamp images can then be used, and it is hoped that this will lead to some improvement in the accuracy of the calibration points.

The reduction of the above sources of error should reduce the error in the absolute value taken from an individual frame from ± 15° C. to about ± 5° C. Moreover, since the variation in exposure time from frame to frame should be almost eliminated, it will be possible to apply the frequency-curve analysis to a series of frames with the possibility of effecting a further slight improvement in accuracy.

It is also proposed to verify the accuracy of the thermocouple observations made with the temperature ring, by carrying out a series of observations with lip-poured casts, using an immersion thermocouple of conventional design in the ladle and comparing its readings with those given by the temperature-ring thermocouple.

The optical pyrometer will be checked on the same strip lamp as is used for calibrating the film, immediately after each observation. In this way, possible changes in calibration caused, for example, by dirt on the objective will be detected at once.

VIII—Acknowledgments

The work described in this paper was undertaken by The National Physical Laboratory as part of the research programme of the Liquid Steel Temperature Sub-Committee* and the Foundry Steel Temperature Sub-Committee,* and is published by permission of the Director of the Laboratory. Thanks are due to Messrs. Hadfields, Ltd., Messrs. Wm. Jessop and Sons, Ltd., and The United Steel Companies, Ltd., for granting facilities for experiments to be carried out in their works, and to Professor Herbert Dingle, of the Imperial College of Science and Technology, who put a grating spectrograph at the author's disposal.

The author wishes to acknowledge the help he has received in discussion with his colleagues on the Committees, and in the observational work from Miss V. M. Leaver of The National Physical Laboratory and Mr. Dennis Knowles of Messrs. Hadfields, Ltd., the latter having taken all the optical pyrometer readings. He is also indebted to Mr. A. Gridley, of the Instrument Workshop of the Laboratory, who made the special shutter and carried out all the other modifications to the camera.

Appendix—*Sources of Error in the Method of Photographic Photometry Employed*

(i)—*Variations in Time of Exposure of the Film*

Each run of the camera was timed by means of a stop-watch capable of being read to an accuracy of about 0·03 sec. The same routine was followed to correlate the operations of the cameraman and the timekeeper for the filming of both steel and strip lamps, and since the lengths of corresponding runs were made approximately the same (6 or 7 sec.), errors caused by the reaction times of the observers should cancel out. By counting the number of frames in each run, the average speed of the camera should be determined to an accuracy of about $\pm$ 1%, though under the noisy conditions under which the steel records were frequently made, one might then reasonably expect a somewhat lower accuracy. Figure 63 is a plot of the calculated values of the mean time interval between successive frames for each shot in two

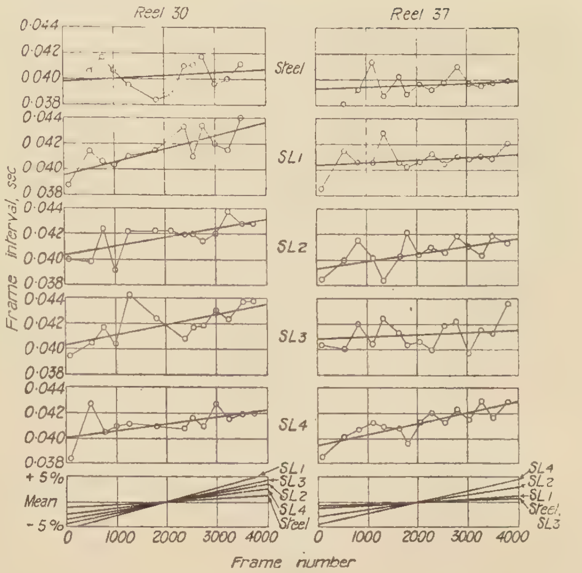


Fig. 63—Observed values of camera-speed variations

representative reels of film. The speed of the camera falls off as the load on the take-up spool increases, but this should not introduce an error if the mean speed throughout the reel is taken for each of the images recorded. The mean straight lines put through the observed points, however, do not all show the same slope, and reference to the curves at the bottom of Fig. 63 shows that if their mean positions are adjusted to equality, then there may be a discrepancy of as much as 4% between two runs at the ends of the reel. For the wave-length in use, this is equivalent to 0·017 in the value of 1/temp. (° K.) or 5° at 1500° C. Since, however, weight is given to the observed density values for all four strip lamps in each run, the final error is not likely to be as great as this, and can probably be safely assessed as less than $\pm$ 3° C. The scatter of individual speed observations about the mean curve is not normally greater than this, and in any case, is probably partly due to uncertainties in timing.

It is possible, however, that even if the mean speed of the camera were known with high accuracy, there might be considerable variations in the exposures given to successive frames owing to unsteadiness in the running of the camera mechanism. To investigate this point, therefore, an independent test of the camera was made. A flash-lamp bulb was fixed to the edge of a disc mounted on the spindle of a synchronous motor and this was photographed while the frequency of the supply was held steady under stroboscopic observation. The length of arc traced by the lamp gives a measure of the time of exposure of the film. Since the camera shutter operates close to the film,

* Now formed into the Pyrometry Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association.

a correction had to be made to the length of the arc according to the positions of its ends in the frame. The corrections were determined by projecting the image on to a screen ruled with radial graduations corresponding to the positions of the shutter at intervals of 0·001 sec.

The results obtained are shown in Fig. 64. Sections of two runs of the camera are recorded ; one in its original condition and another after the side pressure had been eliminated from the camera gate.[1] The camera was fully wound for each run, and the last sections represent the speed just as the camera ran down. The improvement effected by the modification is marked, the tendency to a long-period variation in speed visible in the second curve probably being caused by a slight inaccuracy in the application of the correction referred to above. This experiment suggests that irregular running of the camera may lead to an additional uncertainty of ± 2° C. in the value given by an individual frame (but *see also* section (iii)).

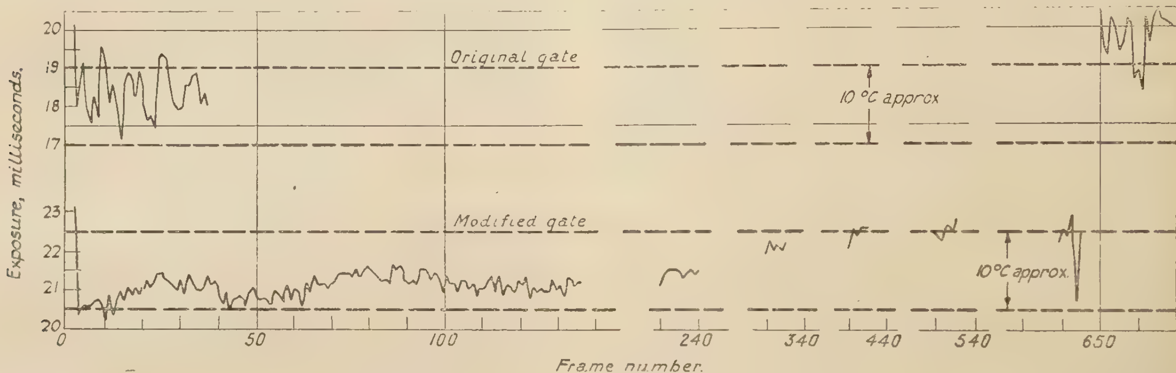


FIG. 64—Frame-to-frame variations in exposure

In each of the temperature measurement runs, the camera was fully wound at the start, and the slight falling off in speed during 6 secs. (150 frames) equivalent to some 2° C. will be the same for both steel and strip-lamp images, so that no appreciable error should be introduced from this cause.

(ii)—*Inequalities in Illumination and Development of Individual Frames*

Since the conditions of agitation of the developer were by no means ideal (the rack of film was kept moving by hand, in a tank of otherwise stagnant developer) it was realized that the degree of development could hardly be uniform over the whole of each frame. Moreover, the presence of reflecting surfaces in the camera and lens might lead to preferential illumination of some parts of the picture space, though, owing to the long focal length of the lens, the cosine effect would be negligible.

In order to investigate this point and to determine any correction that might be necessary, single frames were exposed to a source of uniform brightness. This consisted of a piece of matt opal glass about 20 cm. sq., under uniform illumination of about 10 foot-candles from a lamp at a distance of about 10 ft. in a room with blackened walls. Illumination was normal, and the camera was placed to receive reflected light at a distance of 6 ft. with its optic axis inclined at an angle of 30° to the normal. Exposures were of the order of 1 min. and were made with the single-frame time-exposure adjustment of the camera. Frames were exposed at such intervals that specimens could be selected from a variety of positions between the top and bottom of the developing rack, some having been developed in the erect and others in the inverted position.

Since these exposures were prolonged, any inequalities in the sector opening of the shutter would be ignored. As, however, the opening in the normal shutter is about 190°, a variation of nearly 2° across the frame would be necessary to cause an error of as much as 1° C. in temperature measurement. With the special shutter having an opening of only 12°, however, the condition is much more severe. The sector was cut on a Taylor, Taylor, and Hobson engraving machine in the Instrument Workshop of the Laboratory, and tests made in the Metrology Division showed that the angular opening was constant to within ± 0·1% over the width of the frame.

A second modification to the camera gate was made after the exposure of reel 25. This involved the removal of two bright steel pressure bars which operated on the back of the film just above and below the gate mask. Since this removal might affect the distribution of illumination over the frame, the experiment with the evenly illuminated field was carried out on two reels, 24 and 40. Density contours on one of the six test frames examined on reel 24 are shown in Fig. 65. The test frames of reel 40 showed a very similar density

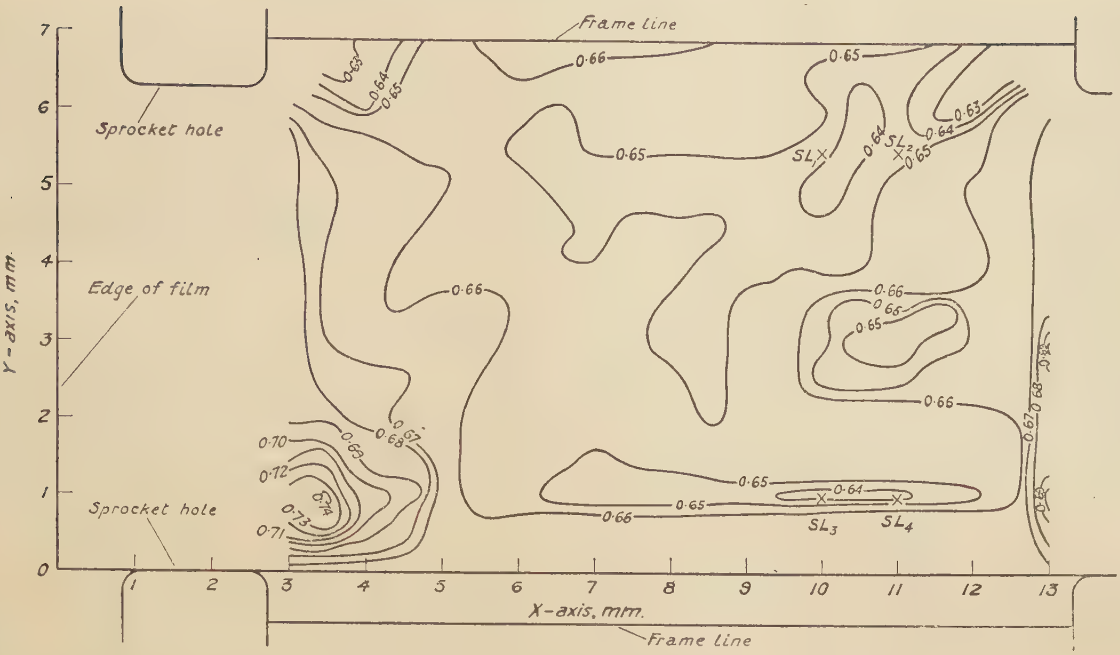


FIG. 65—Density contours on frame exposed to a uniform field

distribution except that the "hump" in the density of the bottom left-hand corner was reduced from the value of 0·1 shown in Fig. 65 to about 0·05. For either camera condition, the distribution proved to be independent (to within the limits of experimental error) of the position of the frame on the developing rack.

Referring to Fig. 65, the left-hand edge of the film and the upper edge of the bottom left-hand sprocket hole are taken as the datum from which the X and Y co-ordinates (measured in millimetres) are measured. The positions of the four strip-lamp images are indicated as SL_1, SL_2, SL_3, and SL_4. They occur in regions of approximately equal density, and the mean density of the four positions has been taken as the standard to which densities in other parts of the frame are corrected. For example, if the image of the steel was being examined at $X = 4$ and $Y = 2$, the correction would be $-0{\cdot}03$.

Since the characteristic region of high density occurred in the same place whether the frame was developed erect or inverted and, moreover, its density was lowered by a removal of bright surfaces in the camera, it seemed probable that it was caused by uneven illumination. That being so, the contours of Fig. 65 might not apply if the whole frame were not illuminated. Two successive frames were therefore exposed to the opal, one as in Fig. 65, and the next with a mask normal to the axis of the camera and between it and the opal. This mask cut the field into four vertical strips of which the width of the images, taken in turn across the frame, were 1·8, 0·2, 1·8, and 0·2 mm. These widths correspond closely with those of the images of an average casting stream and of the strip lamp. The densities measured on this frame agreed closely with those in the corresponding positions on the adjacent frame exposed without the mask.

The reliability of the corrections derived from these experiments may be judged from Fig. 66 and the results given in Table VIII.

The correction used in any instance is the mean given by all the test frames exposed under the appropriate camera condition. The two curves of Fig. 66 show the distribution of the residual

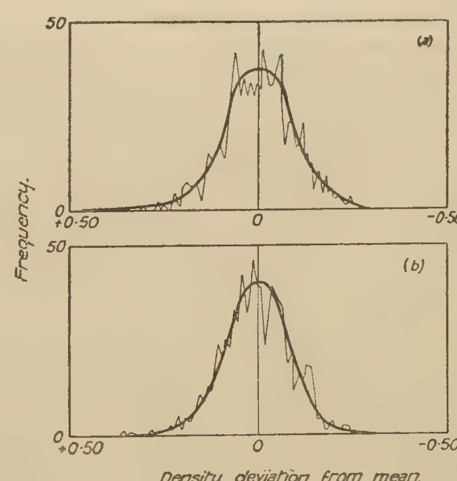


FIG. 66—Frequency curves of the variations in the densities at corresponding points on a number of frames similar to that shown in Fig. 65; (a) reel 24, (b) reel 40

differences between the individual values and their respective means (*i.e.*, the residuals obtained from a table such as Table VIII but repeated over the whole of the "steel" half of the frame, some 850 values in all). Measurement of the areas of sections of the frequency curves, shows that in reel 24 the chances against an individual error exceeding 5° C. (0·016 in density) are about 10 to 1, while after the removal of the bright pressure bars (reel 40) the chance against such an error has risen to 15 to 1. While a single frame might therefore show an error from this source of 5° C. or so it is unlikely that there would be a persistent error as great as this.

TABLE VIII—*Density Distribution Corrections*

Camera Condition.	Correction.							
	X = 4, Y = 1.		X = 6, Y = 1.		X = 4, Y = 3.		X = 6, Y = 3.	
	Observed.	Mean.	Observed.	Mean.	Observed.	Mean.	Observed.	Mean.
Before removal of bright bars (reels 18 to 25)	−0·044		−0·015		−0·016		−0·030	
	−0·024		−0·034		−0·023		−0·020	−0·019
	−0·065	−0·042	−0·026	−0·020	−0·021	−0·020	−0·009	
	−0·041		−0·014		−0·022		−0·019	
	−0·045		−0·016		−0·029		−0·019	
	−0·031		−0·014		−0·006		−0·019	
After removal of bright bars (reels 29 to 42)	−0·028		+0·008		+0·001		−0·006	
	−0·042		+0·008		+0·001		−0·001	
	−0·042	−0·033	+0·021	+0·006	+0·007	+0·002	+0·016	+0·004
	−0·034		−0·003		−0·002		+0·002	
	−0·020		−0·002		+0·003		+0·007	

(iii)—*Irregularity of Development and Sensitivity along the Film*

In addition to local variations in development over the area of a single frame, there are greater variations in density between frames in different parts of the same reel. Such variations can be caused by uneven development and also by variations in sensitivity along the length of the film. In general, frames at the top and bottom of the developing rack show greater density than those between, while there is liable to be a more rapid rate of change of density from frame to frame in this region than elsewhere. In order to take account of these changes, the density of at least one strip-lamp image was measured on every frame which was examined. Figure 67 shows the variation in density of the image of SL_2 as measured at intervals along the length of reel 37. The individual observations are shown in the graph and are connected by a thin line. The values used in the calculations are taken from the mean curve. In drawing this curve, isolated points of abnormal density (such as frame 3262) have been ignored except in such instances as frames 813 to 817, which lie near the top of the rack where sudden irregularities are more to be expected. Sometimes there was an obvious reason for an abnormal density, such as a scratch on the film. When this occurred the observation was not plotted. The departure of individual observations from the mean curve does not in general exceed 0·01 in density (about 3° C.). This variation is, as might be expected, slightly greater than the irregularities in the camera-speed curve plotted in Fig. 64.

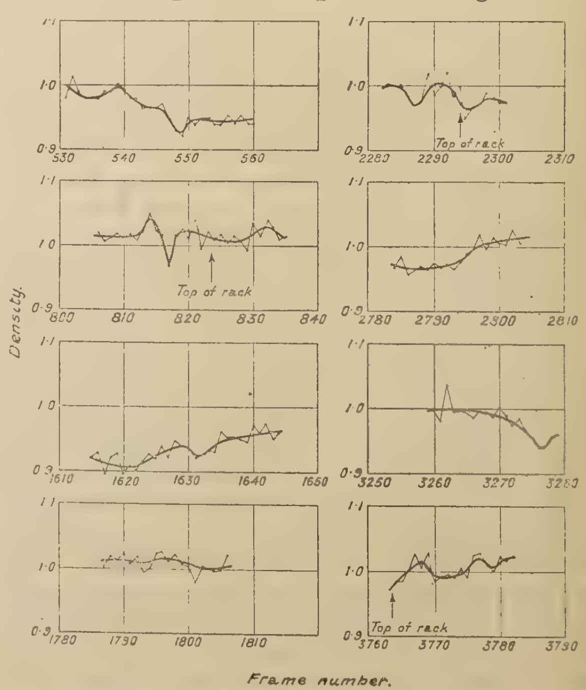


FIG. 67—Variations in density of strip-lamp image along the length of a 100-ft. reel of film (reel 37)

)—*Errors Arising from Time Interval between Observation and Calibration*

There is a possibility of two sources of error der this head. First, the speed of a photographic ulsion decreases with keeping, so that its isitivity would not be exactly the same when was exposed to the steel stream and when it eived the calibrating exposures some days later. cond, the latent image itself may change during s period.

Changes in sensitivity of the emulsion are not ely to be appreciable over a period of three eks or so when the emulsion is a year or more l, and in the present work only emulsions which d nearly reached the marked expiry date for velopment were used. Details of the film used d the relevant dates are given in Table IX.

Experiments were made to investigate the errors iich might occur under these conditions.

Using a reel of film from batch 536, exposures ere made in the laboratory on 17th May, 1945, a source set up to represent an average casting ream in size and position in the frame. This was ne by forming an enlarged image of a strip mp by means of a supplementary lens. Allowice was made for the absorption of this lens in lculating the temperature of the strip lamp. ie normal procedure of calibration of the film was llowed, the calibration images being exposed on th May, 1945, and the value found for the rip-lamp temperature was found to be correct within $\pm$ 5° C. The actual result is shown in g. 1. Evidently no appreciable error was introiced by the storage of the film for an 11-day riod between the exposures on the steel and i the strip lamp.

For the June experiments, an "imitation steel" iage, as described in the paragraph above, was recorded at the beginning of all the reels it was intended to expose, the exposures being made on 15–16th June, 1945. When the density values given by the calibration made on 2–3rd July, 1945, were used, the temperature values given for the "imitation steel" were of the order of 15° C. (0·05 in density) too high. In November, therefore, an extended version of the May laboratory experiment was carried out on a reel of film from batch 586. Advantage was taken of a surplus reel left from those prepared for use in Sheffield in June to include a 5-month-old image in the test. Further "imitation steel" records were made at intervals corresponding to those which elapsed between the various works observations in June, and the same delays as were allowed between those exposures and the calibration exposures and development were again used. The densities of the "imitation steel" images were calculated from the calibration data, and the departures of the measured densities from the calculated values are plotted in Fig. 68. From this graph it appears that there was a growth of the latent image amounting to about 0·0026 in density per day of storage. This involves a correction of about $\frac{3}{4}$° C. per day, and the application of this correction

Table IX—*Dates of Coating, Exposure and Development of Film*

Reel.	Batch No.	Date of Coating.	Date of Exposure.		Date of Development.
			Steel.	Calibration.	
18	545	9/12/43	7/3/45	21/3/45	28/3/45
19, 20	545	9/12/43	7/3/45	22/3/45	28/3/45
21	545	9/12/43	9/3/45	23/3/45	28/3/45
22	536	9/10/43	9/3/45	23/3/45	28/3/45
23	536	9/10/43	12/3/45	23/3/45	28/3/45
24	536	9/10/43	12/3/45	24/3/45	28/3/45
25	545	9/12/43	12/3/45	24/3/45	28/3/45
29, 30	586	21/9/44	20/6/45	2/7/45	30/7/45
33	586	21/9/44	21/6/45	3/7/45	30/7/45
34	586	21/9/44	21–22/6/45	3/7/45	30/7/45
37	586	21/9/44	26–27/6/45	2/7/45	1/8/45
40, 42	586	21/9/44	27/6/45	2/7/45	1/8/45

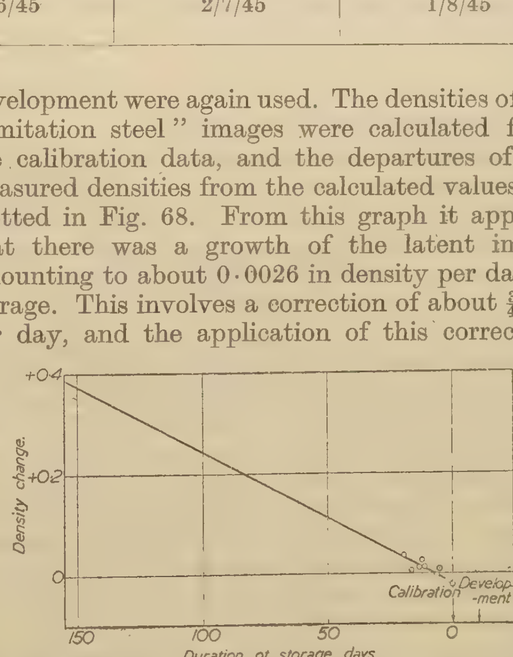


Fig. 68—Change in latent image with prolonged storage

F*

over the appropriate 17- or 18-day interval, accounts for the 15° C. discrepancy in the values found for the "imitation steel" images recorded on 15–16th June, 1945. This correction has therefore been applied to the results of all the June experiments.

Discussion of these results with the research staff of Messrs. Ilford, Ltd., confirmed that the effect was almost certainly due to a change in the latent image rather than to a fall in speed of the emulsion. It is possible, however, that the November experiments might be invalidated by the fact that they were carried out in a laboratory where mercury vapour might be present in sufficient quantity to intensify the image. Since, however, the intensification of the 5-month-old image (which had been stored elsewhere for the intervening 130 days) is so remarkably consistent with that experienced during the last 20 days, this seems to be unlikely. Moreover, the fact that the degree of intensification is consistent with that of the images used as controls in the June experiments, which were stored under yet another set of conditions, reduces further the likelihood of mercurial contamination as being the cause.

Since complete failure to allow for this effect would not affect the observed values for the brightness temperature by more than 20° C. at the worst, the use of an estimated correction should reduce the error to less than 5° C., while with the extra control employed in the June experiments it should be quite negligible. Nevertheless, it is clearly desirable to shorten the interval between the exposures on steel and strip lamp as much as possible.

(v)—*Difference between Visual and Photographic Mean Effective Wave-Lengths*

Since the mean effective wave-length given by a monochromatic filter depends on the "cut" of the filter and the sensitivity curve of the observer's eye or of the photographic emulsion employed, the same glass will have a different effective wave-length when used photographically from that which applies when it is used visually. The H.P.3 emulsion has a peak in the sensitivity curve at the red end of the spectrum, but its sensitivity does not extend as far into the red as that of the eye. Figure 69 is taken from a wedge spectrogram of a tungsten source at a colour temperature of 1658° C. The boundary of the spectrogram was determined with the microphotometer by making a series of traverses perpendicular to the wave-length axis at intervals of 20 Å. The $D = 0{\cdot}5$ isopaque was taken as the boundary. The accuracy of the results may be judged from the graph, and from the results obtained at three colour temperatures which are given in Table X.

The values were obtained from the curves by measuring the heights (on a linear, not logarithmic scale as plotted) at intervals of 20 Å. These heights correspond to BV (brightness multiplied by the visibility function of the emulsion) for each wave-length. The effective wave-length is then given by ΣBV divided by $\frac{1}{\lambda}\Sigma BV$.[2] The effective wave-length of the same glass when used visually is 6444 Å. at 1931° K., while that of the

TABLE X—*Mean Effective Wave-Length Determinations*

Colour Temperature, ° K.	Mean Effective Wave-Length, Å.
1694	6330
1931	6323
2175	6317

glass used in the optical pyrometer (Corning 50% red) is about 6580 Å. Since the emissivity correction varies directly as the wave-length, there will normally be a discrepancy between the photographic and optical pyrometer readings. For liquid steel, the correction is of the order of 120° C. so that if the calibration of the film were made with black-body sources, the discrepancy would be about 5° C. Since, however, the film is calibrated with a tungsten source (tungsten having

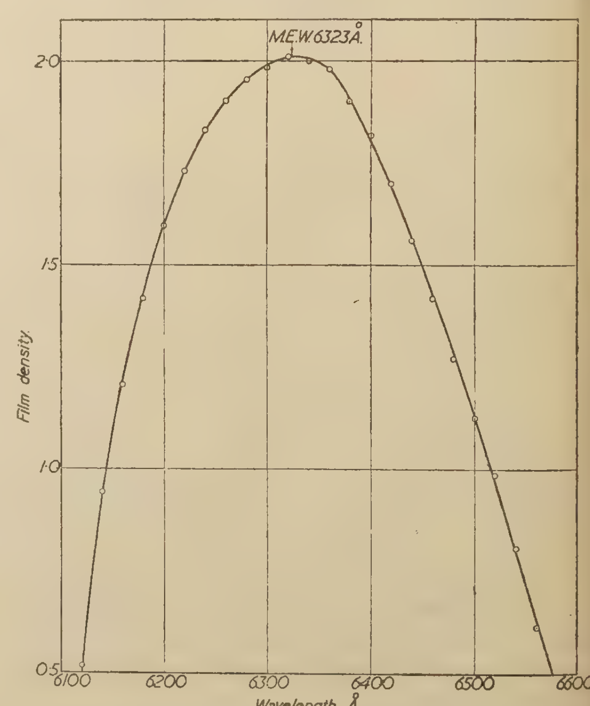


FIG. 69—Curve taken from wedge spectrogram for mean effective wave-length determination

out the same emissivity as liquid steel) the ference is negligible.

Mention may be made of the possibility of slight riations in the effective wave-length for different tches of emulsion, as traces of impurity can use a "tailing" of the curve in the extreme red. is might cause quite large variations in the ective wave-length if the cut of the filter were ry near to the limit of the normal emulsion nsitivity, but this is not the case with the H.P.3 ulsion. The risk would be more serious with me of the slower panchromatic emulsions which e not sensitive so far into the red, but even so, change large enough to affect the temperature easurement appreciably would be likely.

i)—*Fitting of Calibration Curve to Observations*

Owing to the presence of experimental errors, e strip-lamp densities do not lie exactly on a ooth curve when plotted against 1/temp.(°K.) d a mean calibration curve is drawn through them. ie standard deviation of the observations (root-ean-square value of the residual differences from e mean curves) has been calculated. It amounts 7° C. for reels 29 to 42 and 10° C. for reels to 25, the increased value for the latter group ing caused by some abnormally large deviations reel 24.

These deviations are in part the result of the st two sources of error already considered which, r a run of four frames only, would probably tal to about ± 5° C. (*cf.* Table I). The additional error introduced by uncertainty in fitting the calibration curve to the observations is probably only about ± 2° C.

(vii)—*Errors in Densitometry*

Since a barrier-layer photo-electric cell is used as detector in the microphotometer, the sensitivity is high and should enable transmissions to be measured to an accuracy of 1% at densities as high as 2·0. Errors may be introduced, however, by (*a*), non-linearity of response and (*b*), drift of the photo-cell current. A test for non-linearity was made by interposing a neutral filter of about 20% transmission between the light source and the film, and repeating the density measurement which had just been made. No measurable difference between the results was found.

As regards drift, the cell was specially selected for the work, and its total drift after prolonged exposure was only of the order of 2 or 3%. It is very unlikely, therefore, that errors of more than 1% (or 1° C. in temperature) would be introduced. Repeated measurements on the same film confirmed this estimate.

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The Iron and Steel Engineers Group

Formation of the Group

FOLLOWING an announcement, made at the Seventy-Seventh Annual General Meeting of the Iron and Steel Institute, on 1st May, 1946, the Council appointed an Engineering Committee to form an Iron and Steel Engineers Group, and to organize Meetings and Discussions on the problems of Iron and Steel Works Engineering. The present composition of the Engineering Committee is as follows:

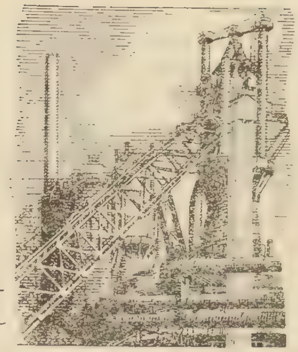
MR. W. F. CARTWRIGHT (*Chairman*)	Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.
MR. W. B. BAXTER . .	Appleby-Frodingham Steel Co., Ltd.
MR. W. R. BROWN, D.S.O.	Messrs. Ashmore, Benson, Pease & Co. Ltd.
MR. H. S. CARNEGIE .	The English Electric Co., Ltd.
MR. M. FIENNES . .	Messrs. Davy & United Engineering Co., Ltd.
MR. E. T. JUDGE . .	Messrs. Dorman, Long & Co., Ltd.
MR. H. H. MARDON .	The British Iron and Steel Research Association
MR. I. S. SCOTT-MAXWELL	The British Iron and Steel Federation
DR. C. H. DESCH, F.R.S. (*ex officio*)	President, The Iron and Steel Institute
THE HON. R. G. LYTTELTON (*ex officio*)	Honorary Treasurer, The Iron and Steel Institute

Membership of the Group is open to all Members of the Institute without additional fee. A circular notice has been sent to all Members of the Institute inviting them to join the Group.

The Iron and Steel Engineers Group will collaborate closely with the Local Societies affiliated to the Iron and Steel Institute and with British and Foreign Engineering Institutions.

A special section of the monthly Journal will be devoted to the proceedings of the Iron and Steel Engineers Group: in this issue, the section opens with a report of the first meeting of the Group, and three papers to be presented for discussion at the third meeting.

The programme and notices of the activities of the Group will be announced from time to time in the News section of the Journal.



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE FIRST MEETING

THE FIRST MEETING OF THE IRON AND STEEL ENGINEERS GROUP of the Iron and Steel Institute was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Wednesday, October 16th, 1946. Mr. W. F. CARTWRIGHT occupied the Chair, and Dr. C. H. DESCH, F.R.S., President of the Iron and Steel Institute, was present at the opening of the meeting.

PROCEEDINGS OF THE MORNING SESSION: 10.00 A.M. to 12.45 P.M.:

The **Chairman**: This is rather a great occasion; it is the first meeting of the Engineers Group of the Institute. With the progress of the iron and steel industry there has been a gradual change from entire dependence on the metallurgist to an almost equal sharing of responsibility with the engineer. To-day in most works of the mass-production type it is common to find the chief engineer holding a position of at least equal importance to that of the chief metallurgist. In recent years electrical engineers have also begun to come to the forefront. Not long ago they were regarded as more of a nuisance than anything else, but now that has been changed.

A sort of vicious circle has arisen, however. Many engineers who could contribute very good papers on the iron and steel industry have not been members of the Iron and Steel Institute because they said that it had no engineering papers of the type that they wanted, and as they themselves were the very people who should write such papers, we never got any farther. A number of engineers in the iron and steel industry talked this over, and comparisons were made with *Stahl und Eisen* and with the American Association of Iron and Steel Engineers; and in this connection it is interesting to remember that the American Association of Iron and Steel Engineers was originally an Electrical Engineers Association. There was a great deal of discussion on the best way of dealing with what was an obvious want. It was felt that in Great Britain it would be a great pity to have a separate association of engineers, as they had in America, and that it would be much better for them to come under the wing of the Iron and Steel Institute. At a meeting of the Council of the Institute in April, 1946, the decision to form a Group was taken, and I was informed that as I had been a very vociferous complainer they would try the poacher as gamekeeper, and that is how I came to be asked to be the first Chairman.

The object, I feel, is to bring together all the engineers and designers connected with the industry; not only those in the industry itself, but those who make the plant for it, and who are obviously as important as the people who run the plant. There has been a gap between us in days gone by. The Committee was formed, therefore, of members of the industry, members of the mechanical engineering side of the design and plant-building industry, and members of the electrical side of those supplying plant to the industry, as well as representatives of the British Iron and Steel Research Association.

The membership of the Group at the moment is 925, but I know that there is a large number of people who still want to join, and there are also many people on the manufacturing side—not in the industry itself—who are not yet aware of the existence of the Group. I hope, therefore, for a very big increase in the membership during the forthcoming year.

As it was desired to begin as quickly as possible and to start discussion throughout the industry and amongst the manufacturers, it was decided that the first meeting should take the form of discussion, because, with the printing difficulties

which exist to-day, printed papers would be out of the question at such short notice. We therefore chose two subjects of general interest to try to get all engineers concerned with the industry, from coke ovens to the finishing mills, to come along and to try to get as many people as possible to speak.

The formation of the Group will in no way clash with any of the established engineering institutions such as the Institution of Mechanical Engineers and the Institution of Electrical Engineers. Only subjects which are special to the iron and steel industry will be discussed by the Group. Similarly, it will not clash in any way with the local societies such as the Lincolnshire Iron and Steel Institute or the South Wales Institute of Engineers, because arrangements have been made for working in conjunction with those bodies.

Dr. **C. H. Desch**, F.R.S. (President of the Iron and Steel Institute): On behalf of the Iron and Steel Institute I wish to extend a very hearty welcome to you all to-day and to express our gratification that it has been found possible to form this Group. The good attendance this morning is evidence of the interest taken in the subject. I must confess that I was surprised to hear from the Chairman of the very large number of people who have already expressed a wish to join the Group. It is quite clear that the engineering aspect of the iron and steel industry has now assumed such importance that there ought to be better opportunities for the experts in that branch to meet together and to discuss their problems.

The subject of engineering in iron and steel works has become extraordinarily complex. So far as mechanical engineering is concerned, I find that the papers on the subject are at least intelligible to a person like myself, but that is not the case with those dealing with electrical engineering. I attended yesterday a meeting in Sheffield of the Rolling-Mill Committee, where we had papers before us on the control of tension and on the general electrical control of rolling mills, and I frankly confess that the papers are beyond me. The extraordinary complication of the electrical circuits used to-day is baffling to anyone like myself who, when taking a course in electrical engineering as a student, had to deal only with D.C.; there was no A.C. in use. It is evident that extraordinary progress has been made in these electrical controls, and I am sure that that is one of the aspects which will receive a great deal of attention from the Group.

I am glad that the Group has been formed, and I wish your meetings all success. I am afraid that I shall not be able to remain for the meeting to-day, as I have to go to Paris; but I shall look forward to the publication of your discussions, and I am sure that the industry can derive great benefit from these special discussions.

DISCUSSION ON STEELWORKS LOCOMOTIVES —DIESEL *versus* STEAM

The **Chairman**: The first subject for discussion is that of steelworks locomotives. I have yet to visit any steelworks in the world where the traffic was not a primary question throughout the works and one considered to be needing a great deal of attention. The question of Diesel *versus* steam locomotives for steelworks' use is a very topical one.

The discussion will be opened by Mr. G. R. Walshaw, on behalf of steam locomotives.

Mr. **G. R. Walshaw** (Appleby-Frodingham Steel Co., Ltd.): Before I begin the discussion, I would like to say how much I value the honour given to me to open the discussion on such an important subject.

I will endeavour to do justice to the cause of the steam locomotive, as a user, not as a manufacturer of this type, although I feel rather like a defendant in a court of law stating his defence before the prosecution have outlined their charges against him.

I am limited, therefore, to giving the characteristics of a locomotive designed to perform the duties required of it in an iron and steel works, and then to stating the advantages of the types described.

There are three types required: Type I, supply-route locomotives; Type II, medium shunting locomotives; and Type III, heavy shunting locomotives.

Type I—The supply-route locomotives have to bring either from the mines or the railway company's sidings the very heavy tonnages of ironstone, coal for coke ovens, or any other raw materials amounting to, say, 2700 tons of ironstone per day alone.

They should be the six-coupled, side-tank type, with other details as follows:

Dia. of cylinders	18 in.
Stroke	24 in.
Tractive effort	24,000 lb.
Weight (loaded)	58–60 tons.
Weight (empty)	Say, 48 tons.
Horse-power (at 8 m.p.h.)	572.

This locomotive will haul a train of 560 tons plus its own weight for a distance of about 6 miles, for one mile with a gradient of from 1 in 100 to 1 in 150, and for short distances with a gradient of 1 in 70.

Type II—The medium shunting locomotive will have as its heaviest duty the slag-bank work, which, in the case I have in mind, consists of hauling four full slag ladles from the blast-furnaces to the top of the slag bank, a total distance of about 1 mile. The last ½ mile has the following contours: 1 in 43 up for 300 ft., 1 in 30 up for 600 ft., 1 in 29 up for 900 ft., 1 in 44 up for 800 ft., and about 200 ft. slightly down hill. The load is 81 tons plus the locomotive, which weighs 35 tons.

These locomotives, the six-coupled, saddle-tank type, should have details as follows:

Dia. of cylinders	15 in.
Stroke	22 in.
Tractive effort	16,300 lb.
Weight (loaded)	35 tons.
Weight (empty)	28 tons
Horse-power (at 8 m.p.h.)	382.

A locomotive built to suit this work will perform with ease all the medium shunting required in an iron and steel works.

Type III—The heavy shunting type must be capable of shunting molten-metal cars from the ironworks to the steelworks, the heavy-type steel-furnace slag ladles from the furnaces to the basic-slag bank, and trains of hot ingots and moulds from the steel furnaces to the strippers and mills.

The hot-metal loads consist of, say, three cars each weighing 130 tons, *i.e.*, 390 tons on the level or for slight gradients, the slag ladle, say, nine ladles each weighing 46 tons, *i.e.*, 414 tons on a level run; the ingot trains vary considerably but are usually about 240 tons on the level. The bogies employed on the ingot trains have central dead buffers and have loads of up to 28 tons per axle.

This type of locomotive should be the six-coupled, saddle-tank type, with additional details as follows:

Dia. of cylinders	16 in.
Stroke	24 in.
Tractive effort	19,000 lb.
Weight (loaded)	49 tons.
Weight (empty)	39¼ tons.
Horse-power (at 8 m.p.h.)	450.

The tractive efforts given are calculated at a boiler pressure of 75%, which in each case is 180 lb./sq. in. It will be obvious that if an engine is standing with full steam up it would be able to start a load 33% greater than that given in the specification and should be capable of using at least 85% of boiler pressure up to about 8 m.p.h.

As to which of the three types given above is most suitable, should be determined by carefully estimating the possible loads to be drawn, measuring all the curves and gradients over which the loads have to be drawn, and by taking dynamometer tests of the tractive resistances of some of the special bogies and trucks. In this last connection it might be of interest to know that a dynamometer test on an actual train of ingot cars gave a starting resistance of 73 lb./ton and a running resistance of 40 lb./ton on level tracks, against a usual figure of 12–13 lb./ton for well-lubricated wagons, and 18–20 lb./ton for those with poor lubrication. The figures obtained, together with the necessary clearances, heights, &c., should all be given to the locomotive designers before the engines are built.

Special attention should be given to the adequacy of the heating surface and grate area of the boilers. Highly-softened and filtered water should be used in the boiler, and the continuous blow-down system should be fitted to each locomotive to ensure an absence of scale and no priming.

The grates should be fitted with self-cleaning bars and special dumping arrangements so that fires can always be kept clean without arduous work by the driver, and without interfering with the work of the locomotive. Such grates last much longer than ordinary firebars and prolong the life of the firebox.

The engine frames should in no case be less than 1¼ in. thick, to maintain rigidity under all conditions. Locomotives which have to shunt the dead-buffered ingot bogies should be equipped with central spring buffers, and have heavy cast-steel bracings fitted between the locomotive frames at each end of the engine in order to make sure that none of the shocks of bumping is transmitted to the cylinders or boiler, and also to counteract the twisting tendency which takes place when only one buffer is in contact round curves.

To reduce wear, all pins, slide-bars, spring-pins, brake-pins, crank-pins, and link motion should be heavily case-hardened or made of Nitralloy steel.

Mechanical lubrication should be as nearly complete as possible. Latest developments include everything except the link motion, thus considerably reducing the time spent in oiling-up. The smaller pins on the brakes and springs can be lubricated from a central hand-pump in the cab of the engine.

All the working parts of each type of locomotive should be standardized, and spare wheels and axles, connecting rods, link motion, boiler and firebox should be kept in stock for each type, thus cutting down to a minimum the time of overhaul.

Nature of Work

When all has been done by design and fore-

thought, the work to be done by iron and steel works locomotives remains a very arduous duty. External heat, heavy shocks, extremely abrasive dust and dirt, heavily punished railway tracks, and stiff curves and gradients result in heavy maintenance cost and a very efficient organization is needed to cope with the upkeep of a large fleet of locomotives.

Advantages of the Steam Locomotive

A steam locomotive built to suit iron and steel works cannot be obtained cheaply. My only recent figure refers to the 16 × 24-in. heavy shunting type and is about £6700, and I understand that the price of a Diesel-electric of the same weight is about double that figure.

For flexibility of performance the steam locomotive cannot be equalled. It is equally efficient at all speeds up to its maximum. Short runs and reasons of safety compel a usual speed (loaded) of 7–8 m.p.h., with very frequent stops and reversals, resulting in an average speed of not more than 4 m.p.h. This the steam locomotive can do fully loaded quite efficiently and still be capable of running lightly loaded at 20 m.p.h., whilst when starting from rest it has a reserve of 33% of power over its rated capacity. Even up to 8 m.p.h. it will be capable of 85% of its maximum, *i.e.*, a reserve of 14%.

The robust construction of a steam locomotive is well known. The experience of many years has resulted in a design which can stand a tremendous amount of abuse and even neglect, whilst accidental collisions or derailments seldom do any serious damage which cannot be put right in a short time. The steam locomotive can work quite close to hot slag, molten steel, and hot ingots without risk to any of its machinery, although the paintwork suffers. Minor defects tend to a proportionate reduction in performance rather than to cause a sudden failure.

In spite of statements to the contrary, only one man is required on a works' locomotive. There is a complete absence of clutches or couplings, and its speed is entirely governed by the amount of opening of the regulating lever. There are no auxiliary engines or compressors, &c., for starting. The locomotive is completely free from the starting difficulty inherent in any internal combustion engine.

In times of emergency almost any kind of solid fuel can be used, perhaps with a slight loss of haulage power but with no damage to the boiler or cylinders. The boiler can be adapted also for oil firing in the absence of solid fuel, provided that due consideration is given to protecting the driver from back-firing.

Ease of repair is another great advantage. The machinery of a steam locomotive is well understood by practically all iron and steel works mechanics, and repairs can be executed in shops with no special machinery. The use of spare boilers cuts out the necessity of employing men other than boilersmiths capable of the simple job of changing tubes or stays. A firebox will last 10 years, the tubes, say, 6–7 years, and the rest of the boiler 30 years. About every 4–5 years the engine tyres require truing-up, and whilst the wheels are out for this purpose, piston rings, brasses, and boiler tubes can be renewed and other minor repairs executed.

It is claimed that a Diesel locomotive can be available 24 hr. per day. The steam locomotive cannot attain this high figure, but with a properly organized system of running-shed work, a steam locomotive can be available for 21 hr. per day for 10 days, after which a day of 24 hr. in the shed suffices for tube sweeping, boiler washing-out, gland packing, reducing brasses, &c. It is important to have a proper maintenance schedule and shed organization in order to carry this system out properly and ensure that engines are kept to their rota. The time required for coaling, watering, and oiling-up is about 1 hr. per 8-hr. shift when 3 shifts are worked.

When a steam locomotive is overloaded it simply stalls or stops, or slips and is stopped. There are no clutches and no electric motors or controllers to burn out and no fuses to blow. Any tendency to slip is revealed at once as the chimney gives instant and unmistakeable warning of slipping and so can be instantly corrected by closing the regulator valve. At maximum loading the steam locomotive can run faster than a Diesel, and probably during a shift can save more time than the extra time used in coaling-up, &c.

Although steam locomotives may be heavier than Diesels of the same power it must be remembered that weight is necessary for retardation and braking power, especially on down gradients.

It must be admitted that the running costs of the Diesel locomotive are more favourable, but although the fuel costs of a steam locomotive are roughly twice that of a Diesel doing the same work, this is counterbalanced to a large extent by the lubrication costs being only about one-sixth that of the oil-engine locomotive.

Mr. **C. C. H. Wade** (English Electric Co., Ltd.): The application of Diesel-electric locomotives to steelworks has, I understand, made great headway in the U.S.A., but conditions in that country differ considerably from conditions in Great Britain, and, while a certain amount of information is available, it might be misleading

to try to apply it directly to hypothetical cases in this country. Experience with Diesel-electric shunting locomotives in this country is confined almost exclusively to the railways. As has been said, railway conditions differ very much from those in steelworks, but the experiments which the railways have carried out—and the L.M.S., after 15 years' experience, are still proceeding with the "Dieselization" of their shunting yards—provide some useful information, and also a direct comparison between Diesel-electric locomotives and steam locomotives on similar work under the same local conditions.

The steam locomotive in question is the L.M.S. class $3F$, a six-coupled tank engine weighing about $49\frac{1}{2}$ tons, with a tractive effort at starting of 20,800 lb. I believe that the steaming capacity of the boiler corresponds to about 600 h.p., which power is of course available only at the higher speeds. The Diesel-electric locomotive is also six-coupled and weighs 50 tons, and has a tractive effort at starting of 33,000 lb. It is equipped with a 350-h.p. Diesel engine.

Under railway conditions a very considerable saving in fuel costs has been found. With coal at 40*s*. per ton and fuel-oil at 9*d*. per gal. the fuel cost per Diesel-locomotive-hour is only about one-third the coal cost per steam-locomotive-hour. There are savings in water charges and in maintenance. Experience hardly bears out Mr. Walshaw's views on lubrication costs, as these costs are working out about equal, and even a small saving has been made on lubrication. The railways have one other saving which does not apply in industrial cases, namely, the reduction of the locomotive crew from two men to one.

It is found possible to get more work per shift out of a Diesel locomotive than from the standard steam shunting engine. This arises partly from the fact that the Diesel provides a higher tractive effort at the low speeds than the steam locomotive, and partly from the better driving conditions. The driver can throw the reversing lever while still travelling at 5 m.p.h. if he wants to pull up quickly and start off in reverse. He is more comfortable; it is simple for him when the locomotive is in motion to go from one side of the cab to the other to see what is happening, using the control provided on each side.

The Diesel-electric locomotive has been shown to be capable of working for 7500 hr. out of the 8760 hr. in the year. It is found that seven Diesel-electric locomotives can do the work done by ten steam locomotives. Mr. Walshaw's figures of the availability of the steam locomotive are very interesting, but I understand that in railway work one does not reckon to get more than 5500 hr. a year, and rather less on an average from the steam locomotives. The figures that Mr. Walshaw gave work out at over 6000 hr.

Mr. Walshaw was on the low side in putting the cost of the Diesel-electric locomotive at twice that for the steam locomotive; it would be more like $2\frac{1}{4}$–$2\frac{1}{2}$ times to-day. Experience shows that the operating cost per locomotive-hour, including interest and depreciation on the capital cost of the locomotive, works out about equal for the steam locomotive and the Diesel-electric if about 4000 hr. are worked by each type of locomotive in the year, but for a larger number of hours the Diesel-electric shows a distinct saving in spite of its higher capital cost. If in any undertaking you require 50,000 shunting locomotive-hours of work per year, you can do it with ten steam locomotives or seven Diesel-electric locomotives. If you do it with seven Diesel-electric locomotives you should at present-day prices save about 2*s*. 9*d*. per Diesel locomotive-hour, or about £7000 a year. In making that comparison a crew of one only is allowed for on the steam locomotive; under railway conditions the saving is just about double the figure I have mentioned. I have worked out these figures from trustworthy information, but they are not attributable to any one particular user.

The general inference is that in undertakings where continuous working is required—six or seven days a week, and at least two shifts a day, and probably three—the Diesel-electric locomotive is an economic proposition, even though its capital cost is $2\frac{1}{4}$–$2\frac{1}{2}$ times the cost of the steam locomotive.

Many prospective users seem to regard the maintenance of the Diesel-electric locomotive as a considerable disadvantage as compared with steam locomotives, with which everyone is familiar. However, many parts are similar and the electrical-equipment system is well known but in fact requires little maintenance.

The Diesel engine is perhaps the item which causes most apprehension, but the engine made by my company has been developed with a view to keeping the maintenance simple, and low in cost. The questions of maintenance and life are to a large extent bound up together; the more maintenance you do, the longer you can expect your apparatus to last. If you are content with merely an occasional dusting, so to speak, you cannot expect a very long life from it. Here again we can turn to railway experience and consider life and maintenance in conjunction. The late Chief Mechanical Engineer of the L.M.S. Railway, Mr. Fairburn, in a paper before the Institution of Locomotive Engineers, said:

"It seems that no major engine parts will normally require replacement within thirty years, other than cylinder liners," and he gave it as his opinion, based on the experience he had had with these locomotives, that the locomotive should have a 30-year useful life without any major replacements. He also expressed the opinion that if a Diesel-electric locomotive was out of service only for the scheduled maintenance operations which they had found necessary month by month, six months by six months, and so on, it would theoretically be available for 98% of its time; in other words, it would be out of service for only 176 hr. per year. The actual availability is 80–85%, taking into account out-of-service hours for all reasons such as refuelling, lack of traffic, &c. Maintenance, therefore, cannot be a very big matter.

When a railway company begins to operate anything new, such as the Diesel-electric locomotive, it naturally starts off with what may be termed precautionary measures, carrying out weekly and monthly examinations to see that all is going well, and it works the maintenance of such vehicles in with its general maintenance system. The railways have found, however, that a large number of the maintenance operations conducted to begin with on a weekly or fortnightly basis can be dispensed with or spread over larger intervals, and this decrease in frequency of maintenance has now reached the stage at which a complete general overhaul is necessary only once in six years. I appreciate, of course, that steelworks conditions are harder, but even if the maintenance has to be doubled it still will not amount to much, and it will mean that the locomotive could be available for 96% of the time, if maintenance is the only reason for being out of service.

The industrial user cannot set up for a small number of Diesel-electric locomotives an elaborate maintenance system, but if he has bought British-built locomotives he is in the happy position of being only a few hours away from the maker's works, and I feel sure I can speak for all the makers when I say that when general overhauls or other specialist operations become necessary they will be very ready to render skilled supervision or specialist assistance. There is no routine maintenance operation which cannot be carried out by a skilled fitter and/or electrician, and I am sure the makers would be very willing to give one or more members of a user's staff a short course at the works.

Mention has been made of the need for robustness on the part of locomotives for steelworks and other industrial uses. I am not going to claim that we are right up to scratch there, but we are not far from it. A number of the railway-type Diesel-electric locomotives were sent in 1940 to the Middle East and taken over by the War Department. I saw some of these locomotives early this year, and they had had a very bad time; they had been cruelly misused by the hastily trained Orientals who were driving them, and had met many of the adverse conditions to which Mr. Walshaw referred; there was a great deal of sand about, tracks had been hastily laid by the Royal Engineers up hill and down dale, and there had been many minor collisions and impacts. In some cases, I am informed, rather large live ammunition had been left lying across the track. I visited one of the R.E. Railway Operating Companies responsible for what may be called headquarter maintenance, and I found that these locomotives stood up so well to all these conditions that when one did come into the shops it was a matter of urgent priority to get it out again, because they were the most useful type of locomotive available out of a stock which included foreign Diesel-electrics and a certain number of straight Diesels. One locomotive that I saw had been chased down a gradient siding by a rake of runaway 40-ton flat wagons. The driver jumped off, the wagons caught the locomotive, derailed it, and it rolled down a bank and came to rest on its roof, at an angle of 45°, with its wheels in the air; twenty minutes later, when officers from a R.E. depot reached the scene, the engine was still running! An officer had to crawl into the cab and turn it off. In reporting this at home, I suggested that a safety device was needed to shut off the engine when the locomotive assumed an upside-down position! That locomotive was ready for service again in a short time.

I am sorry that I have not said much about steelworks. I acquired too late for detailed study Mr. Diamond's paper on the subject before the recent Ministry of Fuel and Power Conference. I want to make one appeal. Is it possible to determine, for your tractive or haulage power in steelworks, some fairly standard basic set of model conditions? I suggest that as a fruitful subject of study for your Group. Mr. Walshaw has put before you a range of steam locomotives which can almost, I gather, be taken off the shelf; probably he has them assembled "all but," as the term is in manufacturing circles. Unfortunately, we are not quite in such a happy position. We have many preliminary inquiries mentioning all kinds of different requirements, and if we are to attempt to meet demands from the steel industry for Diesel-electric locomotives

we look like being faced with the development of anything up to 20 patterns. That is going to be very difficult in these hard times. If any general, standardized basic conditions to be met in the way of curves and gradients, weights to be hauled, and so on, could be established, it would be very valuable for both the manufacturer and the steel industry.

The **Chairman**: I think that there is a great deal in what Mr. Walshaw said about it being a pity that the prosecution did not have to speak first and the defence later! I will now ask Mr. Alcock to speak for the Diesel-mechanical locomotive.

Mr. **J. Alcock** (Hunslet Engine Co., Ltd.): The remarks which I am about to make are, on this occasion, to be in favour of the straight Diesel locomotive which, as you know, is a locomotive powered by a Diesel engine and a transmission consisting of a clutch and a gearbox. I speak as a designer and manufacturer of both steam and Diesel locomotives and must admit that I agree with everything which Mr. Walshaw has said about the steam locomotive. It is undoubtedly absolutely first-class and the only thing which can beat it is the Diesel locomotive.

In making comparisons between powerful steam and Diesel shunting locomotives, the question is always raised as to why there are so few large Diesel locomotives in service and, in my opinion, the crux of the whole matter is the difference in capital cost. Let us consider for the moment the case of the small Diesel locomotive which is so well established to-day that it has almost entirely superseded the steam locomotive. Of the locomotives manufactured to-day weighing less than 20 tons, less than one in every hundred is a steam locomotive. The reason for this is not technical, as most people seem to think; it is purely one of capital expenditure. Small Diesel locomotives can be built so much more cheaply than can small steam locomotives. The various advantages about which we have heard to-day are all possessed by the Diesel locomotive, but it is not these advantages which sell the locomotive, it is the price which effects the sales. At the present time a 20-ton locomotive costs the same whether it is a steam locomotive or a straight Diesel locomotive; over 20 tons the straight Diesel locomotive becomes more and more expensive as compared with steam. The relative costs change as the years go by and possibly next year a 30-ton locomotive will cost the same amount, whether it is steam or Diesel, and two years later that may be true of a 40-ton locomotive, and so on. I am sure that in due course large Diesel locomotive costs will be comparable with steam locomotive costs, and when that time comes there will be no question that the Diesel holds the field.

Mr. Walshaw has referred to the capital cost of locomotives, and we have heard that a steam locomotive with 16×24-in. cylinders costs about £6700 to-day, while Mr. Wade has informed us that a Diesel-electric locomotive costs $2\frac{1}{4}$–$2\frac{1}{2}$ times as much, which means somewhere about £16,000. The cost of the straight Diesel locomotive for the same power and weight comes somewhere between these two figures, that is, approximately £11,000. It is all a question of quantity. As Mr. Wade has said, if there was a standardized locomotive which could be put through the works in batches, prices would come down, and there would be a reasonable chance of the Diesel locomotive competing on capital cost.

The straight Diesel locomotive has many technical advantages which are not always fully appreciated. Mr. Walshaw made the point that from the point of view of the power/weight ratio a Diesel locomotive which was as powerful as a steam locomotive could be a good deal lighter, and he added that weight was what was wanted. I agree, but that is not the right way to look at this question, and many people, including those whose aim is to support the Diesel locomotive, frequently fall into this same trap.

Take, for example, a steam locomotive which weighs 50 tons and has a tractive effort of, say, 22,000 lb. It is very frequently claimed that such a locomotive can be replaced by a 40-ton Diesel locomotive also developing a 22,000-lb. tractive effort, and in actual fact this particular tractive effort can be obtained on low gear by a 200-h.p. Diesel engine. In practice, such a locomotive never can, and never will, replace the steam locomotive. It can only maintain its maximum traction up to 3 m.p.h., and when it comes to braking, its 10 tons lighter weight is a severe handicap. How much better it would be to offer a straight Diesel locomotive weighing 50 tons, which therefore has exactly the same brake power, equipped with a 500-h.p. Diesel engine which can produce a tractive effort of 22,000 lb. up to a speed of 7 m.p.h., which is probably higher than can be maintained by the steam locomotive and, what is more, can do this on second gear and is thus able to produce in addition a maximum tractive effort of 28,000 lb. on low gear up to a speed of $5\frac{1}{2}$ m.p.h. Thus we have a similar locomotive as far as weight, wheel arrangement, and wheelbase is concerned, but able to do infinitely more work than the steam locomotive could ever do, and this is what really matters, particularly in the case of arduous

shunting work such as has to be done in steel works.

Take, for instance, the locomotive with 18 × 24-in. cylinders to which Mr. Walshaw referred, of between 50 and 60 tons weight. It has a tractive effort of 24,000 lb. Mr. Walshaw rightly points out that when that locomotive is overloaded wheel slip occurs, depending, of course, on the condition of the rails. With greasy rails or on a misty morning it will occur very much earlier than it would otherwise, but usually we work on an adhesion ratio of about 5 : 1, which means that if a locomotive weighs 50 tons we expect to get 10 tons on the drawbar before wheel slip occurs. In the case of a Diesel-electric or straight Diesel locomotive we consider that a figure of 4 : 1 can be taken, and we have test figures on dry rails down to 3 : 1. If you want the largest and most powerful locomotive that you can run on any particular siding, it is the minimum radius of curve which settles the wheelbase, and the weight of rail which settles the axle loading. Generally speaking, in steelworks' practice the curves are such that we do not expect to run anything more than a six-wheeled locomotive, and in some instances are forced to adopt a 0–4–0 type. Assuming a rail of 90–100 lb./yd. we can go up to an axle load of 18–19 tons and we then arrive at a locomotive suitable for the job from the weight point of view. In the case of the 0–6–0 locomotive this would mean a maximum weight of 55 tons and a tractive effort of 24,000 lb., but a Diesel locomotive of that weight would enable us to obtain a tractive effort of 30,000 lb.

To develop this tractive effort we require a certain horse-power combined with a gear ratio. Thus we have an option of fitting a 300-h.p. engine which will give the 30,000 lb. tractive effort up to a speed of about 3 m.p.h., or a 400-h.p. engine which will give the same tractive effort up to a speed of just over 4 m.p.h., or even a 500-h.p. engine which will give the same tractive effort up to a speed of just over 5 m.p.h., and here I would like to refer to Mr. Walshaw's remarks about frame strength.

We can easily accommodate a 500-h.p. Diesel engine whilst still maintaining $1\frac{3}{8}$-in. frame plates, 3-in. buffer beams, and in fact all other locomotive details of a particularly robust type. It is here that I should like to make a comparison between the straight Diesel locomotive and the Diesel-electric locomotive. In the case of the Diesel-electric unit the weight of electrical equipment is very considerable and the designer then has to compromise and decide whether to sacrifice horse-power to maintain general robustness, or *vice versa.* As a consequence the best he can probably manage in working to a specified locomotive weight is, say, a 400-h.p. engine unit, and even then he probably has difficulty in accommodating his $1\frac{3}{8}$-in. frame plates.

You will by now appreciate the difficulty in comparing different types of locomotives. As a locomotive designer, I suggest to you that the only fair comparison should be based on locomotive design, that is, particularly as regards wheel arrangement, wheelbase, and axle loading. It is true that we could compare a 400-h.p. straight Diesel locomotive with a 400-h.p. Diesel-electric locomotive, but if it is a fact that the straight Diesel locomotive can, if necessary, be equipped with a 500-h.p. Diesel engine, surely the fairest thing is to compare the 500-h.p. straight Diesel locomotive with the 400-h.p. Diesel-electric locomotive, both these units being the very best that can be produced inside the given specification which is limited by axle loading and wheel arrangement. In criticizing the Diesel-electric locomotive we must also remember that there will be a very big drop in efficiency due to the electrical transmission. Here again we must beware of the term "efficiency," as it is apt to give an entirely incorrect impression. Efficiency in terms of fuel is not really important because the amount of fuel used is very small indeed. It is much more a question of what is happening to the power which is being generated and not being usefully used. It can, of course, only go in heat and the problem which the word "efficiency" creates in the mind of the locomotive engineer is the problem of dissipating the heat which is generated.

I can probably best illustrate this point by taking a locomotive starting a heavy load from rest on a gradient or a severe curve, during which period the maximum tractive effort is required. A tractive effort of about 30,000 lb. at a speed of 1 m.p.h. means a rail horse-power of only about 100 h.p. In order to provide this, the engine of the straight Diesel locomotive has to develop only about 110 h.p., the extra 10 h.p. being lost in the transmission, but in order to provide this same rail horse-power the engine in the Diesel-electric locomotive has to develop about 250 h.p. This extra horse-power has to go somewhere and of course it goes in heat lost. One of the problems to be considered with the Diesel-electric locomotive if there is going to be a great deal of heavy, slow speed work is how to get rid of the extra heat which is generated. Undoubtedly, for this type of work the straight Diesel locomotive is ideally suited ; it lends itself to being geared down to get very big tractive

efforts at slow speeds from a small generated horse-power. It is this very fact, as I have tried to explain earlier, which has been the downfall of many designers who were not satisfied to accept this feature as an added advantage, but insisted upon accepting it as the one and only fundamental advantage of the straight Diesel locomotive, and thus grossly under-engined their designs and found themselves with no performance at all except on their lowest-geared speed.

Referring again to the question of adhesion, I should like to mention an interesting test which I made in our own works' yard a year or two ago. We had on test one of the 49-ton 18-in. "Austerity" 0–6–0 shunting locomotives which we were building in large numbers at that time, while alongside it on another track we also had on test a 200-h.p. 27-ton straight Diesel locomotive. It occurred to me that it would be interesting to couple these two locomotives back to back with a dynamometer between them, and this we did. The results of this test bring out a point which I want to make about steam locomotive tractive efforts at low speed.

Mr. Walshaw said that when a steam locomotive was starting from rest with a boiler pressure of 180 lb. it had about 30% overload capacity, but as a matter of fact the steam locomotive, when starting from rest, is really at a disadvantage, and it is not until the wheels are turning at a reasonable speed that there is any hope of obtaining a steady tractive effort. Under no conditions can you get a steady torque from a steam locomotive such as is produced by the straight Diesel or the Diesel-electric locomotive. The 49-ton steam locomotive to which I have just referred with a tractive effort of 23,000 lb. is very similar to the locomotive with 18 × 24-in. cylinders to which Mr. Walshaw referred. It was up against a straight Diesel locomotive weighing 27 tons which in low gear had a calculated tractive effort of about 6 tons as against 9 tons for the steam locomotive. We found, however, that these locomotives were almost exactly equally matched. They stood there for several minutes taking the load and producing on the dynamometer a tractive effort about midway between the two figures I have mentioned, namely, $7\frac{1}{2}$ tons. In other words, the straight Diesel locomotive was producing a good deal more traction than it was supposed to do on paper, while the steam locomotive was producing less. Such, in fact, does actually occur when starting from rest. On one occasion the steam locomotive caught the Diesel on the hop, as it were, and got away with it once out of nine times, while on one occasion also, the Diesel locomotive did the same thing and got away with the steam locomotive, and the steam locomotive could do nothing to stop it. That gives a very good indication of starting effort and it does, of course, prove the case for the low-weight Diesel locomotive being as good as a heavy-weight steam locomotive on that one point alone, but one point is not sufficient and I would never myself suggest for one moment that a 27-ton straight Diesel locomotive was as good as a 49-ton steam locomotive.

On the question of maintenance, I have several very good instances to show that the straight Diesel locomotive can be a better proposition than the steam locomotive. Many people do not keep their records sufficiently accurately for the information to be of any real use, but on the question of fuel costs I have instances which are 4 : 1 in favour of the straight Diesel locomotive, and figures of 3 : 1 and 2 : 1 have already been given to-day. Lubricating-oil consumption is certainly higher with the straight Diesel than with the steam locomotive, but not unduly; I have figures to show that. In one case, for instance, where a 200-h.p. straight Diesel was working against a 15-in. steam locomotive, there was a running cost for the year of about £300 for the straight Diesel and £700 for the steam locomotive, and that is including everything.

The final point which I want to make about these large straight Diesel locomotives is that although not many of them have been built, on account of the difficulty of persuading the customer to pay the extra price—even in the case of the Diesel-electric, almost the only examples are the railway companies' engines, because the railways are making a big experiment with an eye on long-term policy—these larger locomotives are in fact being built at the present time. The company with which I am connected is building at the moment 500-h.p. locomotives, both eight-wheel-coupled and six-wheel-coupled, with tractive efforts up to 35,000 lb., and this on a wheelbase of only 9 ft. 0 in., which is in itself very exceptional for any type of locomotive of this power, and it will be of the greatest possible advantage on sharp curves and badly laid track, such as we get in the majority of industrial undertakings in this country.

Mr. **E. L. Diamond** (The British Iron and Steel Research Association): In comparing Diesel and steam locomotives for steelworks' use, there are at any rate two hard facts to start from. One is that the Diesel locomotive will save in fuel cost something between one-half and two-thirds, but on the other hand the heavy Diesel-electric locomotive represents in capital cost between two

and three times as much. The balance between the saving in fuel and the depreciation on the higher capital cost will be largely determined by the effect of other less-certain factors, principally the maintenance cost and the service obtained from the locomotive.

Mr. Wade has summarized admirably the experience of the L.M.S. Railway, but we have to be rather guarded in applying their conclusions to iron and steel works. In the first place, the steam locomotive with which the standard L.M.S. Diesel was compared would have a lower tractive effort in proportion to its weight than would be the case with steelworks' locomotives, which have smaller wheels and relatively large cylinders in proportion to the boiler capacity because they have no continuous running to do. Secondly, the L.M.S., with a fairly large number of these Diesel locomotives, has been able to reduce the maintenance costs to somewhere near the attainable minimum for this type of locomotive, and the late Mr. Fairburn made it clear that the savings obtained have been due to the great importance paid to adherence to a definite schedule of maintenance. Thirdly—and I think that this point is vital—the L.M.S. have found that with seven Diesel locomotives they can do the work of ten steam locomotives. I think it is doubtful whether in existing steelworks the work of ten steam locomotives can be done with seven Diesels.

There are many reasons why it is difficult to economize in numbers of locomotives in existing steelworks. There is the type of works layout, for example, where the tracks are nothing more than extended sidings, and two locomotives are required to handle certain jobs simply because there would be endless delays in getting one locomotive round to the other end of the trains. Again, there is the necessity in a steelworks of having particular engines standing by for certain jobs—to deal with hot-metal ingots and so on. There are many examples of that. I think, therefore, that it is doubtful whether the same saving in numbers of locomotives could be attained without extensive re-organization, because the distribution of locomotives is so often a matter of geography.

Mr. Alcock is undoubtedly correct with regard to the starting effort of the Diesel locomotive ; everyone is familiar with the setting back of a locomotive to start a passenger train, but these heavy trains have not only to be started, and steam locomotives in steelworks regularly have to exert their maximum output at speeds of 4–8 m.p.h. continuously. One of the things that the late Mr. Fairburn made very clear is that to get satisfactory service from the internal combustion locomotive, it is most important that the output of the Diesel engine shall not be at its maximum for a large proportion of its working time ; otherwise, the maintenance costs will greatly increase. This may make it very difficult to design Diesel locomotives of adequate power within the limitations that apply in many existing steelworks, particularly in respect of overall length.

There is no doubt that the steam locomotive itself is often required to work in steelworks under exceptionally harsh conditions. I feel that this can be mitigated in future plants by attention to the actual layout of the work itself. After all, the use of shunting locomotives in steelworks is only part of the work of handling of materials. The handling of materials inside works has been studied very thoroughly, but it may be questioned whether it has been studied so thoroughly outdoors, although in essence the problem is the same.

I think the objective of our study of this subject should be as suggested by Mr. Wade, that is, to sort out the duties which locomotives have to do in steelworks and to specify conditions for which perhaps one or two standard types would fill the need.

I think it may be found that where there is continuous movement of material in bulk there are much more efficient ways of moving it than by locomotives. It so happens that, generally speaking, the hardest duties, which it would be most difficult to transfer to Diesel locomotives of comparable size, are of that nature. But there is also a great deal of miscellaneous shunting work in steelworks, which will always have to be done by locomotives of some kind, and probably one or two standard types would suffice to do these duties in a new works where the conditions will be more favourable. If such standards can be agreed upon, I think that there is a very good chance for the makers of internal combustion locomotives to develop designs which could be supplied at a reasonable cost. These designs would need to be adapted specially to steelworks' duties, particularly in respect of structural strength. To gain any economic advantage from them, however, it will be essential to make proper provision for maintenance. I agree that there is nothing beyond the scope of skilled fitters. It is more a question of maintenance organization. One of the most important points in favour of the internal combustion locomotive is its greater availability ; but if when it is due to be repaired it has to hang about and take its place with other work the economic advantage may well be lost.

Mr. **E. W. Marten** (Associated Locomotive

Equipment, Ltd.): Locomotive operation in a steelworks involves very heavy collar work, more arduous and exacting than is met with in normal railway operation. Justification for using a Diesel largely depends on the extent to which advantage can be taken of its capacity for intensive service and it is therefore really misleading to compare unit for unit when considering capital outlay, for whereas the cost of the Diesel may be double, or more, that of the steam locomotive, yet given the conditions it may quite effectively displace two or more steam units—at least that is the experience of main-line railways.

Whilst the Diesel mechanical locomotive has, at any rate in the smaller power range, been developed to a high degree, yet the Diesel-electric system does ensure among other advantages the maximum utilization of engine power under the best conditions throughout the running-speed range. With mechanical transmission the power developed by the engine is influenced by the road speed, there being, of course, the necessity of gear changing under load. Having regard to the heavy and concentrated loads characteristic of steelworks operation, the capacity for a high drawbar pull at low speeds, as claimed for mechanical transmission, applies equally well with the Diesel-electric, with the added attribute of smooth acceleration throughout the power range. Since this approaches 600 b.h.p. for the 18 × 24-in. steam locomotive, and in fact in a recent scheme for a steelworks a power in the order of 700 b.h.p. was required, it is evident that at least for these higher outputs the traction motor has a decided advantage over the clutch and gear-box type, not only because the high torque brings its own problems which can effectively be met by electric transmission, but it would appear from consideration of the revised wheel arrangement consequent with the larger power that the tendency will be for the three-axle arrangement to give way to the double-bogie locomotive. That practically confines the design to electric transmission with nose-suspended motors, the "Bo-Bo" type ensuring an excellent layout with good riding qualities for sharp curves and moderate axle loads. A large number of such units are in operation in the U.S.A. and elsewhere, and no doubt more would have been seen in this country but for the special development involved to turn out a design robust enough to withstand the very exacting demands of steelworks operation.

Mr. **E. R. S. Watkin** (Appleby-Frodingham Steel Co., Ltd.): I am one of the operating people here, and I think that this Group will be of very great interest to us as well as to professional engineers. Many of us are interested in questions of manipulation which we also feel have not received sufficient attention in the metallurgical syllabus of the parent Institute.

I have listened to Mr. Walshaw's case with great interest. It is familiar to me, because I am concerned with the operation of the fleet of locomotives which he mentioned. We have had very good service from the steam locomotive and expect this to continue. I have an open mind on the subject, however, and I am sure that Mr. Walshaw has, apart from the fact that he has undertaken the position of an advocate to-day. We are interested in alternatives, if they are adequate. A great deal of harm has been done to the cause of Diesel locomotives in the past by the excessive claims made for undersized machines.

We find that the starting effort of a steam locomotive is maintainable up to something like 6 or 7 m.p.h. That is the speed up to which you are limited only by the cylinder power; after that the boiler limitations come in. To make a satisfactory comparison, we must look beyond starting efforts, so commonly emphasized in the past, and consider the draw-bar horse-power available at 6 or 7 m.p.h., which is the speed which we tend to reach in the course of shunting and in works haulage operations.

Though we find ourselves with steam locomotives of three main sizes, we shall not continue these differences if we ever start with Diesel power. From a close study of operating conditions, we find that a standard locomotive with a draw-bar horse-power of some 300, and 50 tons in weight, whatever its method of propulsion, would meet most of our requirements. The wheelbase should not exceed 9–11 ft., and very strong, robust construction is essential. One point which has not been emphasized sufficiently is ground clearance. Axle-suspended motors would probably be damaged long before they were worn out. With a jackshaft gear, the main gear would need a very high clearance over ground level.

Availability should be split into two headings; firstly, long-term availability in the course of the year, and secondly, short-term availability during a working shift. With a steam locomotive you can have continuous 24-hr. duty for nine days, followed by a day in the shed for cleaning, washing-out, tube-sweeping, and adjustments. Allowing a month a year, or three months in three years, for major overhaul, you then have a long-term availability of 83%, which is high and does not leave much margin for improvement. On the short-term basis, cutting out meal times and shift changing which are common to all types, there is a possibility with the Diesel locomotive of getting

an additional hour's working time in each shift. This should be valued at the full working cost per hour, and perhaps more, as it would avoid undesirable interruptions in traffic service. Taking geographical and other factors into account, I am confident that if you are given one hour's more working time in a shift, you can gradually re-arrange duties to obtain a one-in-seven reduction in the number of locomotives used.

We should not have any saving at all from manning, as we have only one man on our steam locomotives. Fuel looks as if it might show some promising savings. On maintenance it is difficult to come to any conclusion. The main savings seem to be this one hour's additional availability plus the saving on fuel.

I should like to ask Mr. Alcock how the gear-box is used in the Diesel-mechanical locomotive. In the course of ordinary short-distance shunting movements is the gear-box used in every backwards and forwards movement, or only for longer distances ?

Mr. **J. Parker** (Messrs. McLellan & Partners) : Mr. Wade's request for standardization is an essential of American Diesel-electric locomotive building. The largest manufacturer of Diesel-electric locomotives in the U.S.A. builds two types, one of about 600 h.p. weighing 60 tons and the other of 1000 h.p. weighing about 100 tons. The former is in common use in steelworks, and the latter on main lines. Ease of manipulation is the most striking feature of these locomotives.

The reversing lever of a steam locomotive is usually fitted on one side, an inconvenience to the driver when he is observing the load from the side opposite to the lever, and has to cross his cab to operate it. When " inching " a heavy load, and steam is left on the slide valve, the lever is very difficult to move. Could not the reversing lever be operated by a steam cylinder or similar device ? It could then be " remote-controlled " from either side of the cab, and improve manipulation of the locomotive considerably.

The controls of the Diesel-electric locomotive, being small, are easy to operate, and can be placed as is most convenient to the driver, who can then be provided with a seat. These features, together with the absence of coaling problems, give the Diesel-electric locomotive great advantages over the steam locomotive.

The **Chairman** : I should like to add one point of interest to what Mr. Parker has said. Many of you may know that in America the steelworks traffic is usually run as though it were a separate company. There is a regulation in America that at no time may there be less than two people on the footplate. They both sit in swivel armchairs, one on each side, and when the locomotive is reversed they swing round. The crew for a locomotive is five—one controller, two men on the locomotive, and two on the ground—and many of these internal railway companies are now experimenting with radio control from the controller, who merely calls up No. 6 and says, " Go to track No. 9 and shift eight wagons to track No. 14."

Mr. Watkin said that nose-suspended motors would not be suitable for steelworks, but I have never seen any other type (though there are a few, I believe) in the U.S.A. They always use nose-suspended motors in steelworks, and they seem to build them over there so that they are strong enough to take punishment.

Mr. **F. R. Shaw** (Messrs. Ridley, Shaw & Co., Ltd.) : I speak as an interloper. I would describe myself as a locomotive physician and surgeon, which means that locomotives begin to interest me only when they go wrong. I do not see a great many steelworks locomotives, because they have their own maintenance plants, but my firm does overhaul and rebuild locomotives for many types of works, and I have seen them under working conditions in limestone quarries, gas, and water works, chemical works, and so on. In my opinion, nowhere does a locomotive get worse punishment than in a steelworks, and nobody in a steelworks has a worse headache than the poor works engineer.

Mr. Walshaw said that all the locomotives at Appleby-Frodingham were six-wheelers. They must have very good tracks there. On Tees-side, some of the steelworks have curves so acute that a six-wheeler is to all intents and purposes out of the question.

In my opinion, the steam locomotive is most suitable for steelworks use at the moment, because of its smooth take-off and its flexibility. I am wondering what the effect is going to be on the clutch of the Diesel-mechanical locomotive when moving hot-metal ladles very slowly. As far as general maintenance is concerned, I think that a great deal of the trouble with the present steelworks steam locomotive is lack of sufficient and frequent washing-out. Some of the boilers that come to us are in an appalling condition as far as scale is concerned.

The American method of handling traffic by means of a separate company has been mentioned. I have been seriously considering recently whether it would not be possible in an industrial area such as Tees-side to form a sort of locomotive pool, so that if a locomotive does go out of action there is always a spare available, and the offending locomotive can be taken away and dealt

with. There would then be no delay, apart from the time taken for the transference from the pool siding to the works concerned of a locomotive in perfectly good condition. A separate company might be formed to undertake the overhaul of all the locomotives, so that there would be a constant stream in and out of that company's works, and no steelworks or other works in the area would run short of a locomotive. I do not know whether there is anything in that idea or whether it is worth developing, but I put it forward for your consideration.

Another point in favour of the steam locomotive is the rapidly varying load which it will handle. You can do all sorts of things to a steam locomotive that a Diesel would not stand. In a way, it is a disadvantage to the steam locomotive that it will work under such bad conditions, because often when traffic needs are pressing it has necessary repairs postponed to the last minute, because it will keep going somehow. Eventually, a Diesel, as it works on compression, will flatly refuse to start. It may refuse to start for minor reasons, but there comes a time when because of lack of compression it will not start, and then there is nothing for it but new liners and pistons, whereas the steam engine, even with a ½-in. gap between rings and cylinder, will make some effort to move. That is an important point.

Mr. **J. A. Thornton** (Messrs. B. Thornton, Ltd.): I am not interested in the running or manufacture of locomotives, but it might be suggested that if the Diesel locomotive manufacturers really desired to supply such locomotives to the heavy steel trades, it would be good advertisement for them to design and supply a locomotive to one of our steelworks for, say, a period of six months, and then pass it on to another steelworks. This would enable both parties to decide the suitability and users and manufacturers would then have operating experience to guide them.

The question of payment and price, I believe, would present no obstacle in the event of satisfactory performance being given.

Mr. **F. R. Shaw**: It may interest Mr. Thornton to know that a certain firm on Tyneside, having asked my advice on whether to buy a Diesel or a steam locomotive, thanked me and bought a Diesel against my advice; and I have a bet on with them that in two years they will be sorry!

Mr. **W. Brown** (Messrs. W. Beardmore & Co., Ltd.): I am very glad to be present at this initial meeting of the Group. The large attendance augurs well and I hope that the Committee in charge will be able to produce as good a programme at future meetings.

I want to ask Mr. Alcock a question. He referred to the cost of the Diesel locomotive as compared with the steam locomotive, and then went on to refer to the higher power which could be obtained for a given weight. When he spoke of the comparative cost, did he intend to convey that the higher powers would be available at the price of £10,000 which had been compared with a £6700 steam locomotive of 450 h.p.?

Mr. Wade, dealing with the maintenance of the Diesel-electric locomotives, mentioned that no major replacements are required under 30 years. I think that is a rather misleading statement. What is a major replacement on a Diesel engine? Considerable experience of repairs and maintenance of Diesel engines leads me to ask: What about valves, valve gear, and the increased number of moving parts which go with multiple cylinders? There is also the maintenance of the propulsive means, whether electric or gearing, and an air-compressor. Upkeep costs are the crux of the situation, and manufacturers will need to tell operators more than they have done today to inspire confidence.

Fuel costs, we have been told, will be about one-third to one-half the cost of coal for the same work done by a steam locomotive, but heating and centrifuging may be necessary. Lubricating oil, we are informed, will cost a little more, and the extent of this increase will depend on efficient maintenance of the engine and gear, and on the availability of satisfactory means of cleaning the oil.

Much has been made of the results of experiments by the railway companies with Diesel locomotives, but we must remember that the railway companies refuse to run their locomotives on many steelworks tracks, and that curves and gradients are totally different to those in a normal railway marshalling yard.

Mr. Walshaw has mentioned steelworks atmosphere and dust, and I emphasize that it will be difficult to exclude this from the Diesel engine and its gearing or electrical apparatus.

These factors force me to the conclusion that we had better stick to steam until manufacturers of Diesel locomotives can demonstrate beyond question the economies they claim.

Mr. **C. C. H. Wade** (English Electric Co., Ltd.): It has been suggested that I have made a misleading statement about maintenance. I was endeavouring to quote the exact words of Mr. Fairburn, the late Chief Mechanical Engineer of the L.M.S. Railway, and it was his statement entirely. As to what constitutes a major replacement, it may be remembered that the statement which I quoted said "no major replacement

except cylinder liners," which gives one a clue that a cylinder liner is a major replacement. On the question of valves and so on, I do not remember the figures offhand, but they are to be found in Mr. Fairburn's paper. Valve spring replacements and so on are required from time to time, but they are reckoned as small parts and not as major replacements.

With regard to dust and grit, I mentioned that we had had this type of locomotive operating amid the sand and grit of the Middle East, but we took reasonable precautions against it. All the air admitted to the engine is filtered. The air supply to the generators and motors is filtered air forced through with a fan. We took particular care to make the control cubicle dust-tight, but one oriental gentleman managed to get something alight inside the control cubicle and took a couple of buckets of sand and threw it in; but that is merely by the way. From all that I have heard this morning, the question of atmospheric conditions—grit, filings, metallic dust, and so on—is the one which worries me least as regards steelworks conditions.

Mr. **J. L. Gaskell** (Appleby-Frodingham Steel Co., Ltd.): Would Mr. Wade comment on Mr. Alcock's views on the energy losses in conversion ?

Mr. **Wade**: As I understand the position, Mr. Alcock claims that the instantaneous conversion efficiency is higher with a gear-driven machine than with electrical equipment. I quite agree: I do not think that any electrical manufacturer would make a different claim. In my opinion, however, the matter is not entirely one of instantaneous efficiency; it is the overall efficiency over the shift, over the day, and over the year that matters. Although Mr. Alcock did not have time to give us a great deal of information as to the new mechanical transmissions that may be coming forward, I am still of the opinion that the electrical transmission will give you greater facility of working in general over a period, whether that period is one hour, one day, one week, or any other time.

I am not out to attack the Diesel-mechanical, which I think has its place in the scheme of things, particularly for the smaller powers. I was interested in Mr. Alcock's remarks about the 500-h.p. Diesel-mechanical drive, but after listening to the statements which have been made here to-day, I am wondering what is going to happen in a steelworks, where apparently there are many shocks and minor collisions and rail shocks through obstructions on the track and so on, where you have a Diesel engine with a direct mechanical coupling, if such is the case, to the axles. Every shock felt by the wheels will be, I imagine, transmitted to the engine.

In the case of the Diesel-electric locomotive, you do not have that direct mechanical connection, and the engine is mounted on resilient mountings on a three-point suspension, which prevents even shocks to the locomotive frame taking effect on the engine. In the fairly large experience which we have had now with this particular type of Diesel shunter, we have not had a broken crankshaft. The same cannot be said regarding the earlier experiments of the railways with Diesel-mechanical locomotives.

Mr. **Gaskell**: On the Diesel-electric locomotive, is the bogie arranged for removal as a unit, so that a spare complete with motor can be put in at short notice ?

Mr. **Wade**: With a bogie locomotive, yes. The particular locomotives to which I have been referring by way of example and comparison are six-coupled rigid-wheelbase engines.

Mr. **F. R. Shaw**: It struck me that it might be possible to incorporate a fluid flywheel in the Diesel-mechanical locomotive. This has not been mentioned, and I should be glad to know if it is the case, as it seems that the smoothness of take-up would be an advantage.

Mr. **Wade**: Fluid flywheels have been used.

Mr. **F. R. Shaw**: Mr. Fairburn's opinion did not cover a period of 30 years. His opinion was that the life would be 30 years.

Mr. **Wade**: I quite agree. His experience covered about 15 years, and an aggregate of about 200 locomotive-years—not one locomotive for 200 years, obviously!

The **Chairman**: I should like to ask Mr. Alcock whether the problem of continued drive during gear change has been overcome. If you are going uphill in a car and you have not a clutch stop you have to slam the gear through to change up. If you have a fluid flywheel and self-changing gearbox and you change, the whole car jerks forward with a feeling of shock to the transmission. Has this difficulty been overcome on the Diesel-mechanical locomotive ? When you change up, suddenly altering the engine revolutions from very fast down to the bottom in a matter of seconds, as you do with a fluid flywheel and self-changing gear-box, how do you get over the shock effect on the engine ?

Mr. **J. Alcock**: First of all, I should like to associate myself with Mr. Wade's remarks about dust and air filtration. In my opinion, 99% of the troubles with Diesel engines are due to poor filtration, which may be due to poor filters having been fitted, but is more often due to poor maintenance, and frequently to no maintenance at all.

Reference has been made to bad starting. It is true that when the cylinder liners become badly worn, compression is reduced and the engine is difficult to start, but this again is a question of maintenance and it is not a big job to replace cylinder liners, as and when necessary.

It is also very true that the steam locomotive will run when it is in an appalling condition, but I do not think that that is a particularly good feature ; it simply lends itself to abuse. A Diesel locomotive will not run when it is in a bad condition and so it has to be properly maintained ; that is the reason why so much is said about regular maintenance on Diesel locomotives ; it is in fact essential. To get the best out of a Diesel locomotive, daily, weekly, monthly, and quarterly routine jobs must be carried out and the most important of all these is filtration : filtration of air to the cylinders, filtration of the lubricating oil in the crankcase, and filtration of the fuel oil to the injection pumps. These three sets of filters are quite easy to look after properly, and they must never on any consideration whatsoever be neglected if the engine is to be kept in first-class condition. There is no need to be frightened about maintenance costs of Diesel engines ; in fact, it can almost be guaranteed that they will come out better than steam locomotive maintenance figures if proper attention is given to these points.

The question of major overhaul is confusing. It is a fact that you can run a Diesel locomotive for years, possibly for 30 years, without major replacements of the type represented by putting a new firebox in a steam locomotive. After all, to put new liners in a Diesel engine is only a week-end job ; all Diesel maintenance work can be done in a few days when necessary, so as to have the locomotive in service without bringing it in for overhauls which will take weeks or months, such as you get with steam locomotives.

Capital cost has been referred to, and I was asked whether I based the comparison on a weight or power basis. Mr. Walshaw mentioned a cost of £6700 for a locomotive with 16 × 24-in. cylinders, weighing up to 50 tons, and Mr. Wade said that a similar Diesel-electric locomotive (by which I suppose he meant of similar horse-power and weight) would cost about $2\frac{1}{2}$ times as much. The Diesel-electric L.M.S. locomotives to which he referred are of 350 h.p. and 50 tons in weight, which is very near Mr. Walshaw's figures. I mentioned a figure of £11,000, which was in between, and in doing so I had in mind a similar locomotive in terms of both weight and horse-power, that is, about 350 h.p. and about 50 tons in weight.

It would take a long time to deal with the question of clutches, gears, and transmissions, even in a general way. In the higher horse-powers, hydraulic clutches are frequently used ; that is, fluid couplings. There are, however, several big locomotives in service with friction clutches. The advantage of the main friction clutch outside the gear-box is that you can completely break the transmission while you make a gear change, and, having made the change, the clutch can be re-engaged, and that takes care of any difference in speed between the transmission and the engine. With a hydraulic coupling there are other difficulties, because at high engine revolutions the hydraulic coupling is almost solid ; this is just like trying to change gear on a car without declutching and the timing has to be very accurate.

As a consequence, when a hydraulic coupling is fitted there are two alternatives only. One is to have a special type of gear-box, the speeds of which can be changed under load, while the other is to fit an auxiliary gear-change clutch between the hydraulic coupling and the gear-box. There are several special gear-boxes which are suitable for use with the hydraulic coupling, such as, for instance, the Wilson type, where you have a band brake for getting on to the next train of wheels almost instantaneously as the other is released, and then the difference in speed and load is taken up by the brake bands. The same can be done with friction clutches of various types controlling each gear ; the disadvantages include complications of the gear-box and the fact that brake linings operating in the oil are apt both to contaminate and to heat-up the oil, which also has to be used for lubricating the gears and the bearings.

There is invariably a break in between gear steps, the combination of hydraulic coupling with gear-boxes of the type which I have just described cutting this down to a minimum. There is also a comparatively new gear-box developed by The Hydraulic Coupling & Engineering Company and referred to as their *S.S.S.* box, which during the period of changing from first to second gear, applies a clutch which operates top gear in order to try to overcome the complete loss of tractive effort between the gear-steps.

Personally, however, I am a great believer in simplicity, and if we can have a straightforward constant-mesh gear-box, with case-hardened, ground gears always in mesh, and a change which can be accommodated by some heavy internal gear clutch, I consider that we have the best and certainly the simplest and most robust gear-box obtainable. We must then have freedom from the

engine while we make the change, and that cannot be done with a hydraulic coupling, which meets one of the points raised by Mr. Wade, about continuity between engine and road wheels. We must have a friction clutch behind the hydraulic coupling simply to take care of the gear change.

As regards the actual effect of a break in tractive effort during gear changing, I must say that we do not find it in service to be much of an inconvenience, and, in fact, in some cases we have even found it an advantage, and this applies particularly in fly-shunting, and in this connection I should like to refer to Mr. Watkin's question of whether we change gear very frequently. This depends very much on the horse-power available and the tractive effort required. With a large steelworks steam locomotive of 500 h.p. you will probably have a gear which at 7–8 m.p.h. would give a 20,000-lb. tractive effort and so you would engage that gear from rest and stay there. You would normally have a four-speed or six-speed gear-box, depending upon the maximum speed required, but undoubtedly for slow speed and marshalling work where 7–8 m.p.h. is a suitable speed at which to run, gear changing would not be necessary.

On some of the latest gear-boxes completely automatic changes are made and the driver knows nothing about it at all. These developments have been coming along over recent years in order to compete with the fact that on the Diesel-electric locomotive the control is simple and the same can now be said of straight Diesel locomotive control. The driver simply controls the throttle lever when he wants to go faster or slower and the changes are made for him, when the engine speeds are in correct relationship with the rail speeds. On the point raised by the Chairman about changing gear when going uphill, such changes are carried out in about one second. In obtaining a quick change of this type, a clutch stop is certainly necessary, but it is purely automatic, and in practice the timing is such that it does not give rise to any difficulties at all.

Mr. **H. Burton** (The British Iron and Steel Research Association): Mr. Alcock made a point of the light weight of the straight Diesel locomotive as compared with the weight of the Diesel-electric and the steam locomotive, and suggested that that light weight, far from being a disadvantage from the point of view of adhesion, was actually no disadvantage at all. The reason for it not being a disadvantage, as I see it, lies in the fact that whereas an adhesion ratio of 5 : 1 is used for steam locomotives, for straight Diesel drive the ratio of 4 : 1 can be used. I should like to ask why the ratio can be dropped from 5 : 1 to 4 : 1 where a straight Diesel drive is concerned.

The only reason that I can think of is that the ratio of peak torque to mean torque with a Diesel locomotive is probably lower than in the case of a steam locomotive, with fewer cylinders, and that is particularly the case when we have in view very low speeds or starting from rest. That would account for the conditions in the test that Mr. Alcock mentioned, where both the Diesel-mechanical and the steam locomotive were operating from standstill, so that the adhesion ratio question was in favour of the former. With the Diesel-electric locomotive, there is no fluctuation of torque whatever during the revolution of the track wheels ; the torque is completely uniform, so that I do not think that there is any advantage as between the Diesel-mechanical and the Diesel-electric in that connection. The lower ratio of 4 : 1 can be taken to apply to a Diesel-electric, and hence because of its greater weight it is possible to obtain a greater tractive effort. I do not know whether that is correct, but I should like to hear Mr. Alcock's views.

Mr. **J. Alcock** : The remarks just made are perfectly correct and I am sorry that I did not make my original point quite as clear as I had intended. The Diesel-electric locomotive and the straight Diesel locomotive both have the advantage that the starting torque is more even than in the case of the steam locomotive and, therefore, you can obtain a 4 : 1 adhesion ratio with both Diesel types as compared with the 5 : 1 adhesion ratio for the steam locomotive. On the question of weight, let us assume that you require the most powerful locomotive which you can obtain. The limiting factor is invariably the curve and the weight of rail. The maximum axle load permitted on your particular sidings may be anything from 18 tons to 21 tons. If you have very sharp curves indeed this may demand an 0–4–0 type of locomotive ; alternatively with curves of 100-ft. radius or more you could probably accept an 0–6–0 locomotive, in other words, your conditions settle the maximum weight of the locomotive, and the maximum traction depends directly upon the weight and on no other factor, although indirectly other factors are, of course, adjusted to suit.

Starting, therefore, with, say, a 50-ton locomotive, the designer has to produce a unit with all the usual robustness and factors of safety and embodying the most powerful boiler or Diesel engine possible within the weight restriction, this larger power unit simply giving maximum tractive efforts at higher speeds, but not influencing in any way the maximum tractive effort

available at low speeds, as this is entirely settled by the weight, as previously mentioned. We now, therefore, come to the crux of the whole matter, with a 50-ton steam locomotive, we get a maximum tractive effort of 10 tons (22,400 lb.), the speed up to which this can be developed being about 6–7 m.p.h., after which it falls away fairly rapidly but, nevertheless, at a speed of, say, 20 m.p.h. it can still produce a traction of about 6500 lb., which means that it is developing well over 400 h.p. From the 50-ton Diesel-electric and straight Diesel locomotives, we can obtain a 12½-ton traction (28,000 lb.), but in the case of the Diesel-electric locomotive due, firstly, to the fact that on account of the heavy electrical equipment, the biggest engine which can be incorporated is something under 400 h.p , and also owing to the efficiency of the electrical transmission at slow rail speeds, this traction can only be maintained up to about 2 m.p.h., when it falls away very quickly, while at 20 m.p.h. it is only about 5,500 lb. In the case of the straight Diesel locomotive, however, the transmission, although extremely robust, allows an engine of something over 500 h.p. to be fitted. Under these conditions a maximum traction of 28,000 lb. can be maintained up to a speed of 6 m.p.h., and although it drops away quickly in steps through the gear changes, it is, nevertheless, well over 8,000 lb. at 20 m.p.h. The straight Diesel locomotive, therefore, lends itself, owing to its fundamental principle of design, to producing the highest obtainable tractive efforts at higher relative rail speeds.

Mr. **A. B. Washington** (Metropolitan-Vickers Electric Co., Ltd.) : I want to put one question to Mr. Walshaw about the figures he quoted in connection with the dynamometer car tests with, I think, a special type of ingot car. The figures he quoted for track resistance in motion, that is, excluding the effort required to give acceleration and any due to grades, were 73 lb./ton during starting and 40 lb./ton when running. These figures would of course be regarded as very high if they pertained to ordinary railway wagons of, say, 12 tons capacity and fully loaded to a gross figure of, say, 18½ tons. They do seem high even for steelworks practice, but many factors come into this question, and before making further comment I should, therefore, like to ask further particulars of those tests. What type of cars were they, what total load per axle, type of axle box and lubrication—presumably not of the roller type—rail weight per yard, ballasting, &c. ?

Steelworks no doubt have very bad conditions to contend with in the maintenance of axle boxes, track, &c., and that might be an explanation of the high figures quoted, but if they are at all common in such works, it is quite essential for manufacturers of these locomotives to have at least such particulars as I have requested, whenever a scheme of locomotive haulage is being considered. These remarks will, I hope, reinforce Mr. Walshaw's emphasis that all conditions affecting track resistance should be made available, if necessary, by dynamometer car tests. Mr. Walshaw also mentioned grades, curves, &c., and with this I fully agree.

It is perhaps not fully appreciated what a large effect the value of track resistance does make on the required weight and horse-power of a locomotive. As against a track resistance of, say, 25 lb./ton, a value of 73 lb./ton when starting would, even on a level track, require approximately twice the weight of locomotive, although, with appreciable grade working, the difference would not be as great. The difference in horse-power rating would also be correspondingly greater.

Mr. **G. R. Walshaw** : The high figure was taken on ingot cars with white-metal bearings with an oil bath underneath, and all the cars were of the same type. We have since developed roller-bearing wheels on these ingot cars, but they are not all converted yet. The roller bearings make for much easier running, but we have 150 of the old cars still in use. The real trouble about the starting loads is that the cars are shunted into the melting shop and stand there for a considerable time before the moulds are filled up with molten steel, and they stand for about 40 min. before being shunted away, with the result that the axle box dries out and there is very heavy resistance to starting. Also, the sand and the abrasive dust in the melting shops get on the axles and cause very severe bearing conditions. There is no doubt that after being run for a short distance, the lubrication is established and running resistances drop, but the same hard conditions re-occur at each visit to the melting shop and the locomotive has to be designed to overcome the high resistances encountered. As for axle loads, we get as much as 64 tons on the car, or 32 tons per axle. The rails on which these cars run are 110-lb. rails, though many of the sidings have 95-lb. rails. The wheel diameter is 2 ft. 0 in., with an 8-in. axle.

Captain **C. A. Ablett** (Cooper Roller Bearings Co., Ltd.) : I should like to offer my hearty congratulations on the liveliness of this meeting, which has appealed to me very strongly. Many of the speakers, in talking about locomotives,

have treated the tugging of a heavy load involving a draw-bar pull of 28,000 lb. as though it were an unfortunate necessity, and have spoken about steelworks limitations in the matter of curves, light rails, and so on. But is this heavy pull an inescapable difficulty ? I happen to be a roller-bearing manufacturer, and so I see the solution.

I should like to remind you that during the last war almost every type of gun was fitted with roller bearings so that it could move easily, and when you consider roller bearings on the trunnions of 16-in. naval guns it does give you something to think about.

The **Chairman** : It is hoped to use Captain Ablett's prize for papers which are read before this Group, and so I am particularly glad that he spoke. He may be interested if Mr. F. W. Jones can give the figures for the resistance of ingot bogies fitted with roller bearings. We have now carried out dynamometer tests on roller bearings.

Mr. **F. W. Jones** : You could push the bogies by hand after they were fitted with roller bearings. It became a joke in the works that one man could push a bogie.

Mr. **L. Griffiths** (Messrs. Guest, Keen, Baldwins Iron & Steel Co., Ltd.) : We carried out some dynamometer tests at Margam and found that the starting effort on roller-bearing ingot bogies was about 9 lb./ton, and that the tractive effort required after setting the bogie in motion dropped to 4·5 lb./ton.

A test made on rolling stock with white-metal bearings in good condition gave a starting effort of 38 lb./ton and dropped to 19 lb./ton when the vehicle was in motion.

Mr. Walshaw's figure of 73 lb./ton has been obtained, but with defective bearings under bad conditions.

The above tests were made on a straight and level track.

As to the availability of steam locomotives, we have taken out some figures from 1st January of this year to date and find that at Margam and Port Talbot Works the locomotives are under steam for 72% of their time, but, for various reasons, the actual time worked is only 41%.

This latter figure is the real availability.

Mr. **E. L. Diamond** (The British Iron and Steel Research Association) : I am not surprised at Mr. Washington's amazement at these figures, but anyone who has seen steel being cast on these ingot cars with liquid metal often overflowing over the bearings will hardly expect figures comparable with railway practice. To make matters worse, it is sometimes the practice, if an ingot will not readily come out of the mould when stripping, to bump it on the car, which does still more harm to the bearings. It is a question for serious consideration whether the present practice of teeming ingots on cars is ideal. The ingots have to be handled by cranes when cast, again when stripped, and again when put into the soaking pit. It seems inefficient to use locomotives to do double shunts with every ingot between each operation under such difficult conditions, unless it is impossible to arrange for the operations of casting, stripping, and soaking to be carried out in close proximity to each other.

Mr. **T. Carruthers** (Workington Iron and Steel Co., Ltd.) : Mr. Walshaw, Mr. Wade, and Mr. Alcock have each put up an excellent case for each of three different types of locomotives.

We are all accustomed to the use of steam locomotives, and it may be useful to know if anyone present has actually used a Diesel locomotive in a steelworks and, if so, what type, and with what success.

Most of us are limited in our choice by the lay-out of our works, which have developed from old-established sites, and the tracks often have curves of short radius, which fact appears to rule out the consideration of the Diesel-electric locomotive, which is apparently made in the 0–6–0 type only, or, at any rate, to limit its use very considerably.

The Diesel-mechanical locomotive is, I believe, made in the 0–4–0 type. Has anyone experimented with it in an iron and steel works ? I am not referring to the experiments which were made a few years ago with Diesels of low power, which, of course, could not be used seriously, and which, unfortunately, gave Diesels a bad reputation. I am referring to Diesel-mechanical locomotives of 200–300 h.p. and of modern design, as we appear to be limited to the use of this type only for most of the internal traffic. Until the use of such a locomotive has been actually tried out under steelworks conditions, it will be nearly an impossibility to say with certainty whether such a locomotive will be satisfactory or not.

Mr. **W. Morgan** (Whitehead Iron & Steel Co., Ltd.) : At Whitehead Iron & Steel Co., Ltd., Newport, we have two Diesel-mechanical locomotives and three steam locomotives ; I am therefore in a position to give my views on the performance of Diesel *versus* steam, and trust that it will help this discussion. At Courtybella Works we have a site of 42 acres, with 58 sets of points and crossings, and 4½ miles of railroad feeding seven rolling mill bays ; therefore, the sidings are congested. The gradients are 1 : 60–1 : 30, and many curves are at 120-ft. radius. From experience I can thoroughly recommend and give a very favourable report on

the performance of a 137–150 b.h.p. mechanical Diesel, this locomotive being ideal for general works shunting. The weight is 29 tons and the tractive effort is 15,000 lb. at a 1st speed of 3 m.p.h. There are four speeds, the top speed being 10 m.p.h. This locomotive will haul on the level 720 tons in 1st, 2nd, and 3rd speeds. I have witnessed a test with this locomotive and found that it pushed a load of 170 tons without being overloaded up to a gradient of 1 : 60 with tandem crossings and a curve at the bottom, the train consisting of coal wagons in a poor condition. Regarding running costs, a careful check was kept on this locomotive for a period of six months, that is, for maintenance, lubricating oils, pool gas oil, and cleaning materials, and the costs were found to be 1*s*. 1*d*. per hour, which you will agree is very satisfactory. A number of previous speakers stated that the maintenance costs on Diesels are extremely high, but I disagree. Minor jobs of cleaning filters, &c., are expected, but maintenance costs are still low. After 4400 working hours one of the locomotives was recently decarbonized and this was carried out at a week-end by the manufacturer's "service after sales" agreement. I am comparing this Diesel with our steam locomotives, which are the six-wheel coupled type, with details as follows :

Dia. of cylinder	15 in.
Stroke	20 in.
Tractive effort (at 75% cut-off) ...	14,300 lb.
Weight (empty)	27 tons.

Fuel costs on this size of locomotive only amount to 4*s*. 6*d*./hr., taking coal at 50*s*./ton. Labour, washing-down, water, &c., must be added.

Regarding operation, it is sufficient to say that our Diesel drivers, who were previously steam drivers, much prefer to operate the Diesel, and changing gears, &c., presents no difficulty to them. From experience I have no hesitation in confirming Mr. J. Alcock's statement that Diesels will beat the steam locomotive every time.

Mr. **C. C. H. Wade**: There seems to be an impression that, because I took as an example a 0–6–0 Diesel-electric locomotive, that form of locomotive is the only possibility. I assure you that that is not so. The 0–6–0 locomotive was developed at the request of the railways of this country, and is, so to speak, the main item on view at present, but Mr. Cartwright will tell you that almost every Diesel-electric locomotive in the United States is a bogie locomotive, and as soon as the demand arises here you will find British manufacturers coming forward with a bogie locomotive to meet it.

Mr. **J. W. Greenwood** (Messrs. Thomas Firth and John Brown, Ltd.): We have steam locomotives and one Diesel. Our Diesel has given us excellent service, and I can say at once that Mr. Shaw is going to lose his bet. In our experience it is much better than the steam locomotive; it will do everything that the steam locomotive will do, except fly-shunt, and we dare not fly-shunt in our works.

On the question of standardization, a wheelbase of 9 ft. has been mentioned. Our steam locomotives all have a wheelbase of 5 ft. 6 in., and the Diesel has a wheelbase of 6 ft. 3 in., which is the limit for our works. I suggest that if we are going to go in for standardization for the straight Diesel for steelworks we might send out a questionnaire and probably get the two wheelbases of 6 ft. and 9 ft. I think the straight Diesel will be the locomotive for steelworks in the future.

The **Chairman**: I think it is obvious that if Diesel-electric or Diesel-mechanical locomotives are to make any progress in this country there will have to be some form of standardization. One of the big American shunting-locomotive firms has made 3500 of two types in the last eight years, and this naturally gives them the opportunity to lower their capital cost in relation to steam locomotives. Until we do something of that nature, I cannot see very much progress being made, because when people go before a board and say "The price of a steam locomotive is £6000 and of the equivalent Diesel-electric £16,000" they will be told to buy the steam locomotive in most cases.

Mr. **G. R. Walshaw** (*replying to the discussion*): The discussion has been mainly concerned with the upkeep of the internal combustion engine itself, and nothing at all has been said about such things as buffers, drawbars, axles, springs, wheels, tyres, brakes, and so on. I think that the steam locomotive has suffered a good deal in the comparison, because there is all this "chassis" work to maintain, and that is added on to the figures of the steam locomotives, whereas the figures given us for Diesels have been purely on the Diesel engine itself, and perhaps its gear-box. If a Diesel-electric or Diesel-mechanical locomotive is going to stand up to steelworks conditions it is liable, like the steam locomotive, to have its buffers knocked off and its springs broken; its brake blocks must be changed, and sand will get in the axle-boxes because one cannot put filters there. Even a Diesel-electric locomotive will want its brake-blocks changed every few weeks. I would like to have more information given about the "chassis" of the Diesel locomotive, and its maintenance in iron and steel works.

With regard to the maintenance of the Diesel

engine unit itself, I have obtained the following information regarding the life of various working parts, which does not bear out the statement that 98% availability can be obtained.

My informant, who is an oil-engine designer, states :

"The life of the engine of the Diesel locomotive will depend greatly on its speed and rating.

Smaller engines running at 1000–1500 r.p.m. require :

(1) Every 200 hr. ... Clean sprayers and all filters. Check big-end nuts.

(2) Every 1000 hr. ... Remove heads and grind valves. Clean exhaust pipes and decarbonize.

(3) Every 2500 hr. ... Draw pistons for examination. Renew small-end bearings, adjust main bearings and big ends. Descale waterspace, clean radiator.

Drain sump and fill with 4–6 gal. of fresh oil every 300–400 hr. Oil consumption 6–8 gal. for 300 h.p.

Larger engines running at 600–900 r.p.m. require :

(1) Every 200 hr. ... Clean sprayers, swill-out and clean all filters. Check big-end nuts. Clean exhaust pipes.

(2) Every 2000 hr. ... Decarbonize and grind-in valves. Check camshaft drive chains for tension.

(3) Every 3000 hr. ... Draw pistons for examination. Examine all bearings for wear. Thoroughly clean-out all lubricating-oil pipes. Descale jackets and radiators. Clean oil cooler.

(4) Every 1600 hr. ... Drain sump, clean out and fill with fresh oil ; approximately 1 gal. per 10 h.p.

30,000 hours should be regarded as the absolute maximum that can be expected from pistons, liners and bearings.

A period of 10 min. per shift is required for filling up with fresh fuel oil.

The above figures, which conform to naval practice in all details, show that more attention and maintenance of Diesel locomotives is necessary than is commonly stated.

Putting controversy on one side, my own view is that there is a large amount of shunting in the incoming and despatch sidings of iron and steel works, where good quality railway wagons are universally used, which a Diesel locomotive will cope with quite easily. Probably 300–350 h.p. would be quite adequate. For slag banks, melting shops and blast-furnaces, however, further development of the Diesel locomotive is needed before it will stand up to the very arduous conditions.

It has been suggested that the real solution for the ingot-car problem is to fit roller bearings to all the cars, and my experience bears this out, but the change over is expensive and in the event of a spillage of molten steel over the wheels, which occasionally happens, the roller bearings are a complete loss, whereas the ordinary white-metal bearings can be run-up and used again. The cost of conversion is about £300 per car.

I would urge those who are thinking of trying out a Diesel locomotive in their works to get the fullest information possible about all the conditions it would have to stand up to, and to bring in the designer to see these for himself before designing the locomotive.

I agree with Mr. Carruthers that the best way to obtain experience is to try one out and develop the design in the light of that experience.

When I first entered iron and steel works, everything was driven by steam engines, even the overhead cranes. We know the advance which has taken place since then in electrical and other systems and this advance can be secured in other directions if engineers get down to it.

The meeting then adjourned from 12.45 *p.m. to* 2.15 *p.m.*

Written Contribution

Mr. **P. F. Grove** (John Miles & Partners (London), Ltd.) : It is perhaps interesting to note that after an inspection of a large iron and steel plant by the electric supply authorities to examine causes of dirt on insulators, it was found that the major trouble came from the steam-locomotive sheds. In a modern integrated works the products of combustion are largely consumed, and there is mostly grit to contend with, but this does not foul insulators in the same way as tarry products of partly consumed locomotive fuel.

In order to reduce smoke, direct electric traction has been considered and there are one or two installations abroad. Except in a few special cases, however, it does not appear that the clutter of trolley wires or other means of collecting current with the attendant dangers and troubles can compete in cost or efficiency with the alternative self-contained Diesel-electric locomotives.

There are also a number of situations in an iron and steel works where self-contained electrically driven cars are used for conveying ore, coke, &c., but they are nearly always sources of danger and constant maintenance, and here again small Diesels or Diesel-electric traction would be a welcome substitute.

(*The afternoon discussion will be published in the February Journal.*)

THE BLAST-FURNACE OF TODAY

PART I—A REVIEW OF CURRENT FURNACE ENGINEERING*

By W. R. Brown†

It is not proposed to trace in detail the developments which have led to the British blast-furnace of today, nevertheless a brief glance at what happened in the period between the Great Wars will help to distinguish the furnaces which form the subject of this paper from their predecessors. Roughly, the period 1920–1940 can be divided in two parts : The first (1920–1930) saw attention concentrated on hearths of 12–16 ft. in dia. ; the second (1930–1940) showed an advance in hearth diameters to 16–20 ft. There were of course exceptions, some very prominent, but, on the whole, these figures indicate the progress.

During the war years there was only a negligible amount of furnace construction, and so we arrive at the commencement of the present reconstruction period which, for the purposes of this paper, is exemplified by those furnaces which during 1946 were on the designer's board, under construction, or have been completed within the year. This present era shows every prospect of being identified by hearths of 20–25 ft. in dia. The dimensional characteristics of these categories can be compared in the composite drawings, shown in Fig. 1, compiled from the lines of half-a-dozen furnaces taken from each period.

In the 1920–1930 group, hand charging had almost disappeared in favour of mechanical charging. No particular method of charging showed an outright ascendency over others. There was a variety of bucket chargers and both single-skip and double-skip chargers. The next period (1930–1940) showed opinion crystallizing almost exclusively in favour of the double-skip charger. Similarly in 1920–1930 distribution of materials entering the furnace was attained by means of a variety of equipment, amongst which were the Brown top, the Clements top, the McKee distributor, and a number of appliances closely related in design to the last-named. With the arrival of the 1930–1940 period the use of the authentic McKee distributor became general. Another feature, the externally spray-cooled steel-plate bosh, was frequently met in the 1920–1930 period but disappeared in 1930–1940. From these, and many other indications, the clear inference is that, whereas our furnaces once wavered between Continental and American design, since 1930 they have followed the latter almost entirely.

There is no point in disguising the fact that designers in this country have enjoyed great benefit from America, where the natural opportunities for expansion gave rise to rapid development. The lead has consequently remained with them and an admirable spirit of collaboration persists between their leading engineers and ours.

If we seek to discover what milestones mark the route to our present position, it would not be unjust to recall the mild sensation caused by the building of the Dagenham furnace in the early 'thirties. Here was an installation which set a new standard in its "streamlined" conception, from ship unloading to pig casting, in the then unusual automatic refinements, in the labour-saving devices, and in bold capital outlay wherever this was justified. The marked impression caused by the Dagenham plant was due to the unique opportunity afforded by a virgin site, coupled with the fact that completion coincided with the emergence of the industry in this country from a grave depression. Independent thought, and some which owed inspiration to Dagenham, led to the creation of several fine plants in the same period. The other great achievement of that decade can hardly be regarded as a milestone on the route to today, for it has not yet been passed or surpassed. The Appleby-Frodingham South Plant, from an engineering point of view, is undoubtedly the most thorough conception that exists in this country today. The extensive preparation of raw materials, the bedding and handling equipment, the clarification and purification of water, together with the general boldness of design and lavish use of high-class auxiliaries makes the plant outstanding and one which is in most ways ahead of the 1930–1940 class.

It is thus that the stage is set for our entry into the 1946 reconstruction period. In engineering matters our best existing plants are not far behind the leading ones in other countries, though this state of affairs is by no means general. In output per furnace we lag behind, but with our

* Received 2nd December, 1946.

† Messrs. Ashmore, Benson, Pease & Co., Ltd., Stockton-on-Tees.

present plants this was planned to conform with the requirements of other sections of the industry. The chief departure which will mark the coming era is the concentration of output in a smaller number of units of a decidedly larger size, together with an overall increase in pig-iron capacity. To achieve this there is no reason why the output of some new installations should not compare favourably with those of other countries.

In examining what is already being done towards this programme, attention may first be turned towards plant layout. As yet, no new development of a virgin site in this country has reached an advanced stage, but the tentative plan of a Dominion plant can be taken as typical of current ideas. This layout (Figs. 2 and 3) embodies no radical innovations, but is notable for the following features :

(*a*) The bin system is purposely low, and incoming materials (already crushed and screened) in bottom-drop hopper wagons enter by an inclined ramp at the east end and the empties are evacuated down another ramp at the west end.

(*b*) The sinter-material bins form a continuation of the main furnace bin system, and crushed

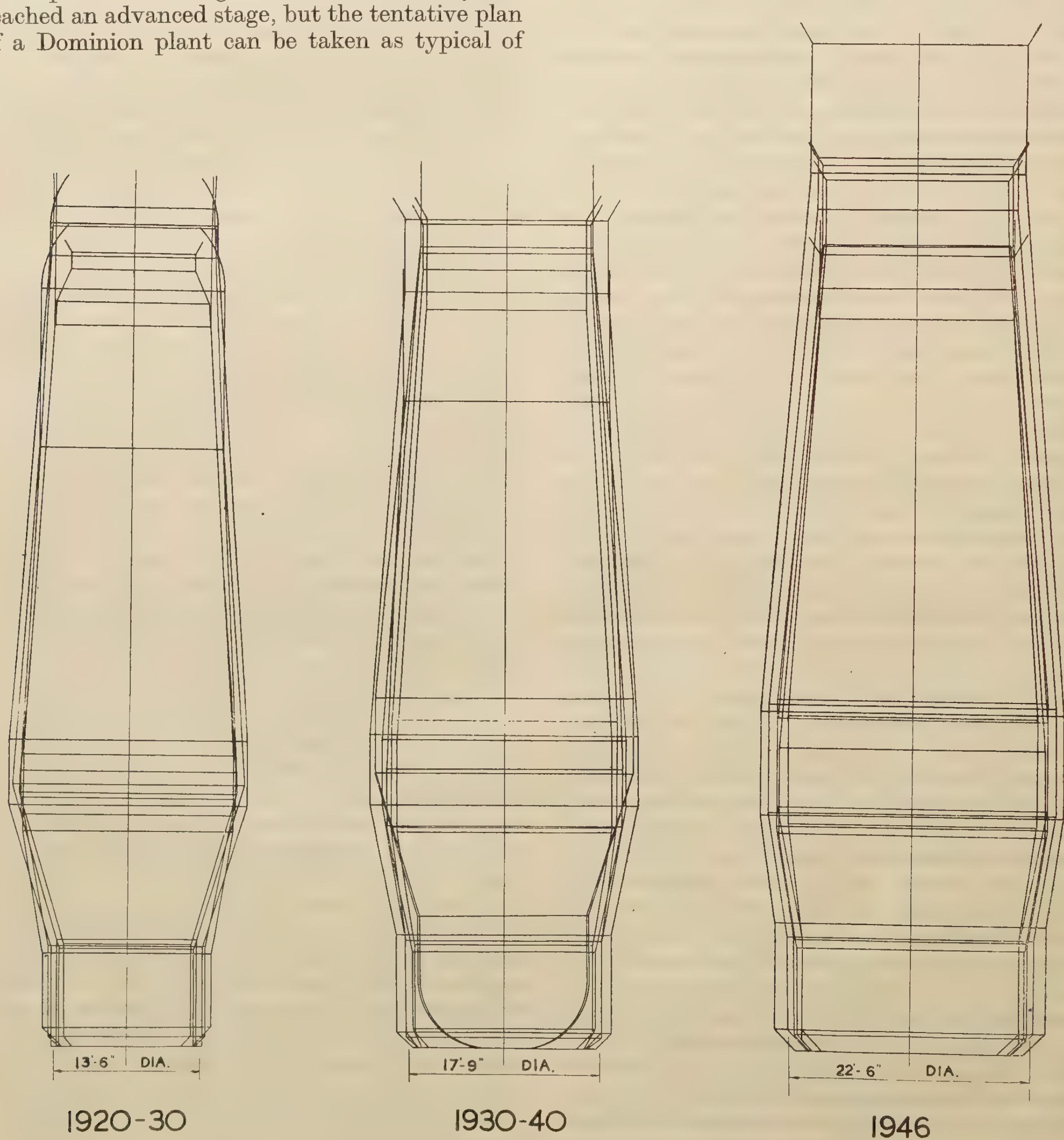


FIG. 1—Composite drawings of furnace lines

or fine ores can be dumped in the appropriate bins or in stock, with all traffic flowing in a uniform direction.

(*c*) The sintering plant discharges into the ore yard where, by means of the ore bridge, the sinter can be stocked or passed by transfer car to the furnace bins. The stocking of fine ore and of sinter permits either the furnaces or the sintering machines to work independently of the other without any costly rehandling of materials or adjustments to the furnace burden.

(*d*) The provision of road access to each cast house allows motor lorries to be used to deliver under each cast-house crane.

(*e*) Railroads are arranged to allow ladles to be moved at any furnace without interference with others. Each cast house is also served by a labouring track from which wagons can be loaded or discharged with the cast-house crane.

There are not many occasions when all the advantages of an undeveloped site are offered to those who are planning new blast-furnaces in this country. Usually we must compromise by adapting an existing site to a new plant and the new plant to the existing site. The result may be far from satisfactory if the planner does not exercise sufficient ruthlessness in eradicating everything which does not aptly lend itself to the new scheme.

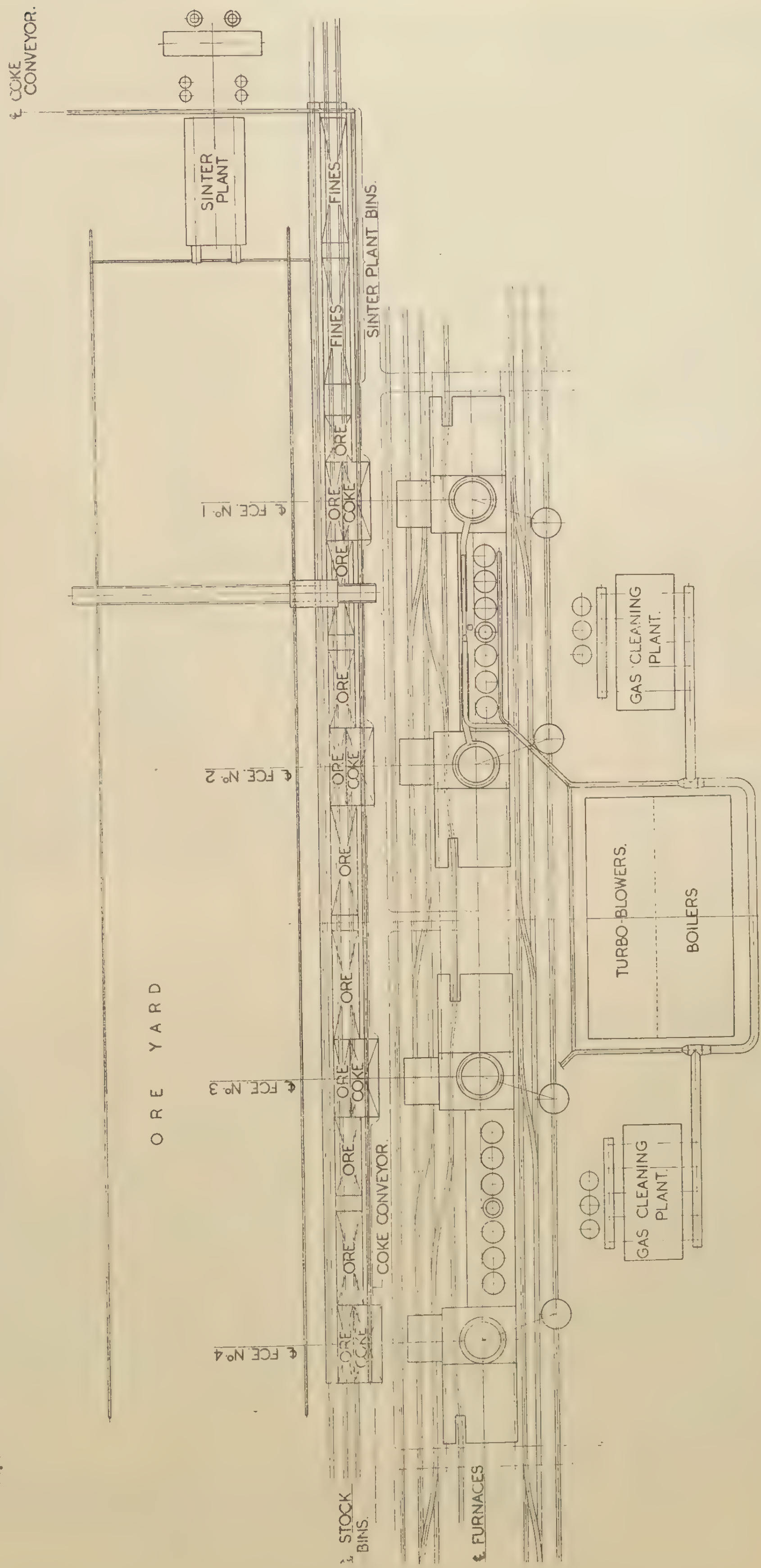


FIG. 2—Arrangement of a four-furnace plant

Whilst dealing with layouts, the plan of one projected cast house merits mention. The problem is how to arrange suitably the slag and iron ladles at furnaces which will make 500 tons of iron per day and 600 to 700 tons of slag per day. The solution has been to devote both sides of the cast house to slag ladles and to place the hot-metal ladles on tracks which traverse the cast house diagonally (*see* Fig. 4). This results in admirably short iron runners. Only two hot-metal ladles will normally be required at each cast, but a third stands in reserve at either furnace.

The handling and stocking of raw materials in this country is subject to such diversified conditions that one standard method of treatment can hardly be expected to emerge. However, whilst 20 years ago there existed only one orthodox stockyard/ore-bridge/bin combination, there have since been several installations of this nature. The larger furnaces of 1946, and onwards, will most emphatically bring into prominence the high-duty, extremely reliable, ore bridge. It is neither practical nor economical to hold large quantities of raw materials in bins, and a stock pile is in most instances necessary. The stock pile is a helpful means to dilute variations in analysis, though only a bedding system will deal adequately with aggravated variations. A remote stock-yard throws a strain on the traffic system; hence everything points to a moderate bin system, backed by a spacious stockyard, served by one or more ore bridges. Many alternative arrangements are necessitated by local conditions, but the operator will prefer the orthodox whenever it can be so arranged.

No major departures in furnace charging from that which was common in the 1930–1940 era are at present contemplated in this country. The size of scale cars (Fig. 5), skip hoists (Fig. 6), &c., is growing proportionately to the increased rating of furnaces. Coke will be automatically screened and weighed or measured by volume (Fig. 7). The responsibility of the scale-car

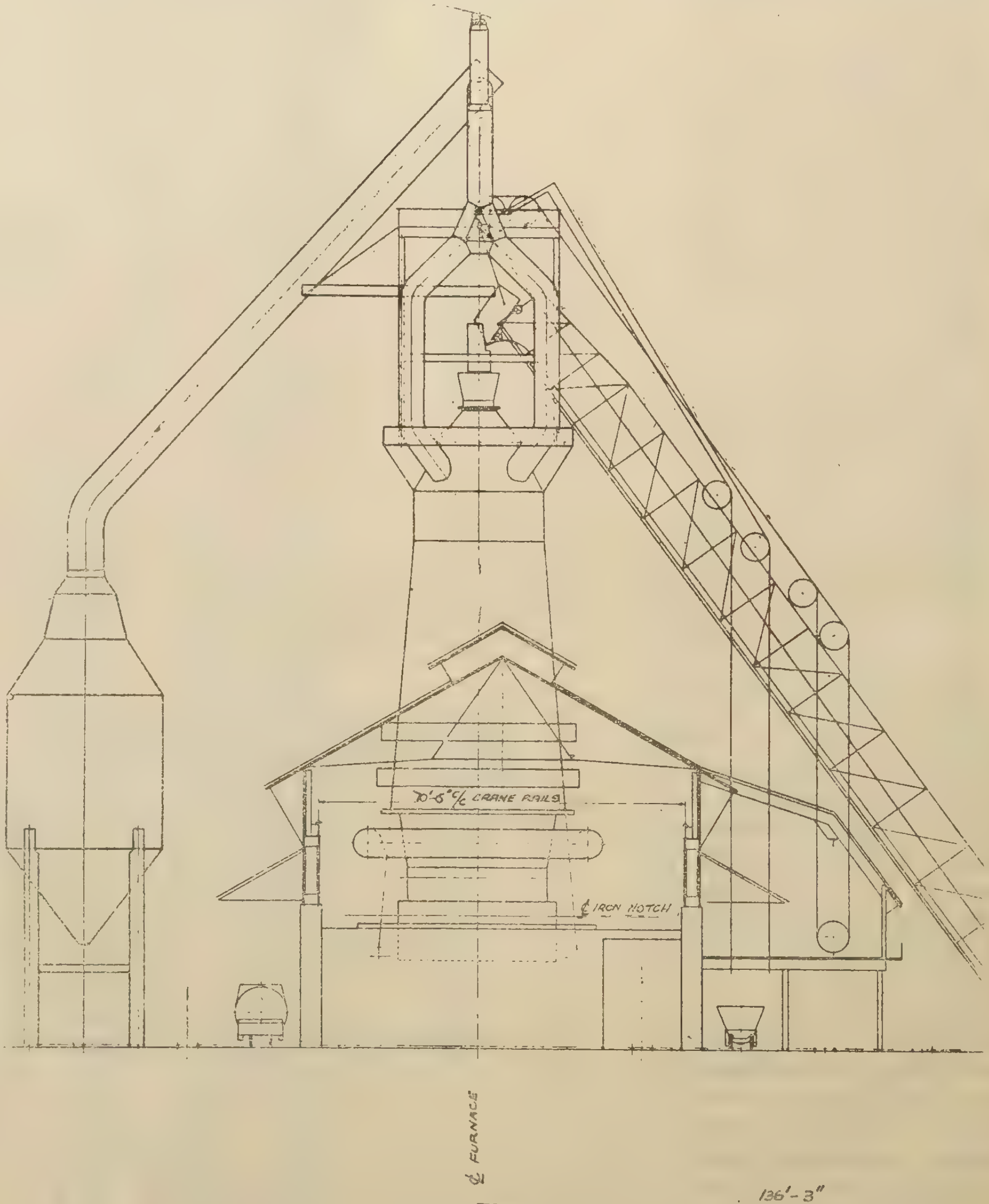


FIG. 3 (*a*)—Sectional elevation of a modern blast-furnace plant (*see* Fig. 3 (*b*))

driver will be practically confined to weighing the materials conscientiously, for in all other respects his operations are rendered mistake-proof. His only duty will be to start the sequence of operations of the charging system by once pressing a button for each charge dumped from the scale car. The coke is charged in a pre-selected number of skips and the sequence started automatically, thus allowing the driver a longer period to collect the ore and limestone. The charging control (Fig. 8) has reached a stage where every possible variation in the routine can readily be applied ; so many contingencies are catered for that the only weakness lies in the operator's ability to memorize the full versatility of which his equipment is capable.

A modern charging control panel is depicted in Fig. 9. What can be accomplished by the equipment is described in the notes to the illustration.

The skip hoists of furnaces now under construction are very similiar to those used in 1930–1940 ; a single-motor drive through double-helical reduction gears, with magnetic braking, is used, a Lilly controller and gravity-set brake safeguarding against overspeed and overwind. The hoist for some of the larger furnaces will be provided with a dual-motor drive in which the combination of motor characteristics and gear ratios will give a speed/torque curve more closely in line with theoretical requirements.

The Freyn pneumatic bell hoist (Fig. 10) is likely to prove by far the most popular method of opening and shutting the large and small bells. This and the McKee distributor are both fundamentally the same as their counterparts of 10 years ago, but a number of refinements in detail have been introduced as the result of further experience.

It will not suffice for designers to content themselves with perfecting the present-day methods of charging and distribution. Detailed research and experimentation have disclosed that these methods give rise to imperfections in the composition of the stock column, resulting in the uneven ascent of the gas. The fact that good results are now being obtained with correctly proportioned orthodox equipment does not rule out the possibility of still better results if known irregularities are avoided. As furnaces increase in size, the shortcomings of the present system of depositing materials on the stockline are likely to become more pronounced ; hence there is a growing inducement to determine whether the ideas of our research workers can offer results radically superior to those which content us at present. It will take some courage to experiment with the costly innovations that are suggested, and the responsibility is not one that can be undertaken lightly by a single individual or firm. Perhaps some means can be devised whereby the industry as a whole can sponsor full-scale tests.

The furnace stack of 1946 does not vary a great deal from its predecessors, but the larger units of this era make possible a most desirable reduction in the number of columns. When a moderate-sized furnace had 10 tuyeres, designers shrank from trying to support the lintel on

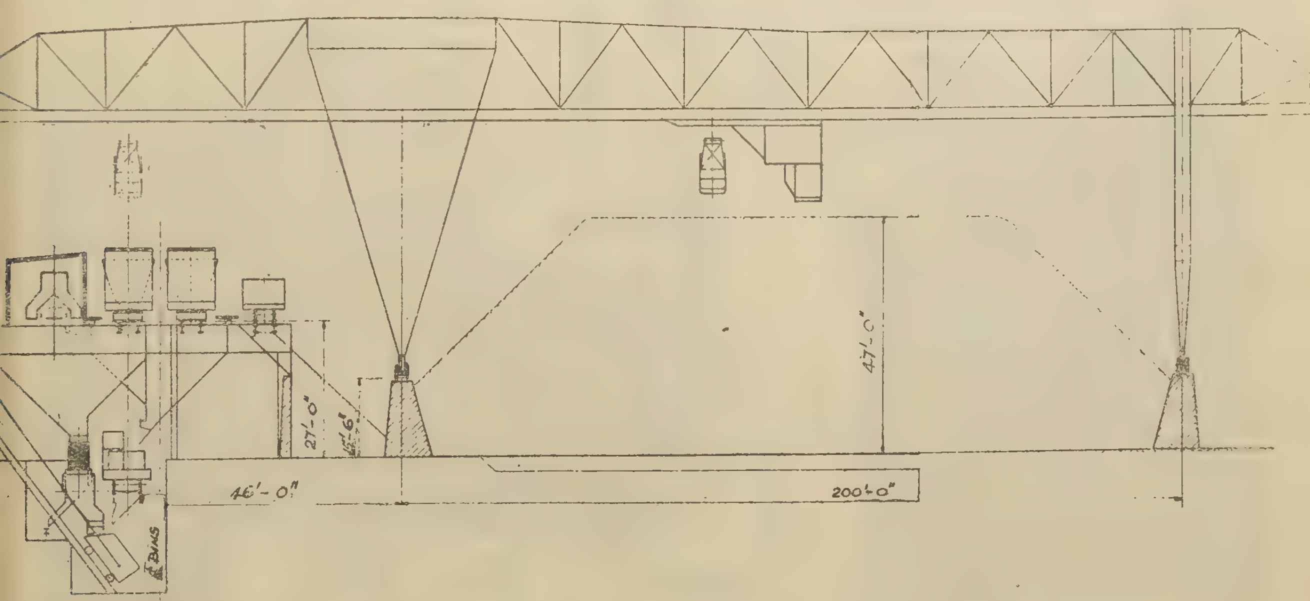


FIG. 3 (*b*)—Sectional elevation of a modern blast-furnace plant (*see* Fig. 3 (*a*))

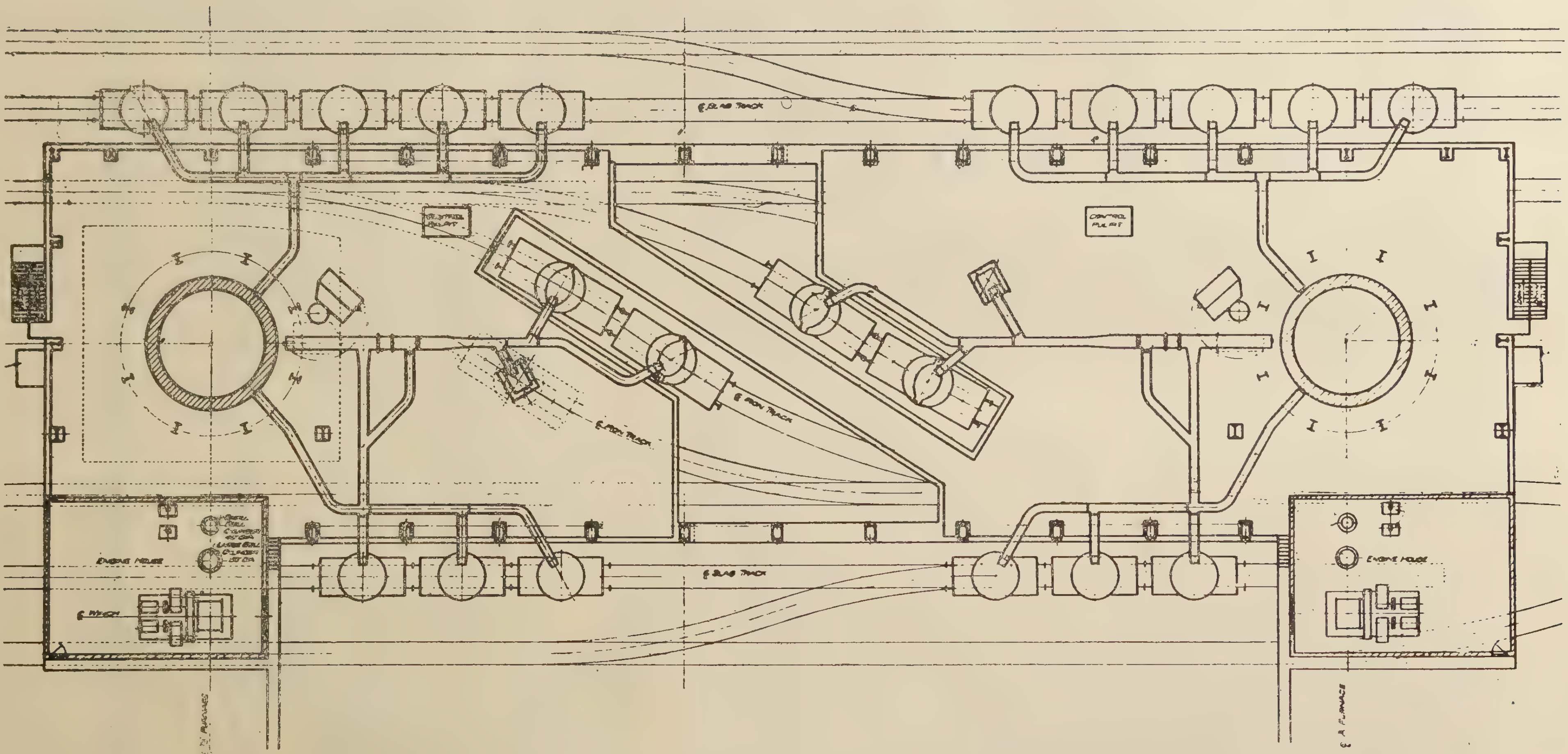


Fig. 4—Layout of cast-house floor for furnaces making a large amount of slag

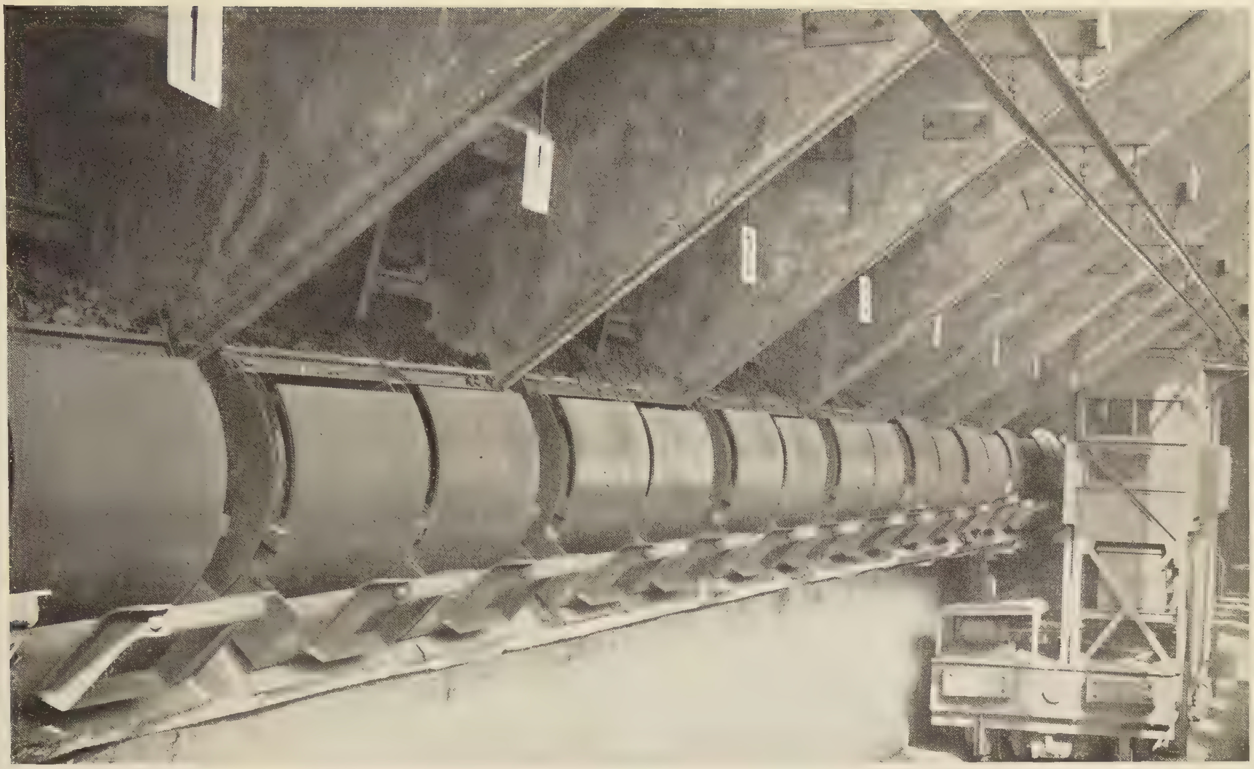


FIG. 5—Scale car and double-lip bin gates

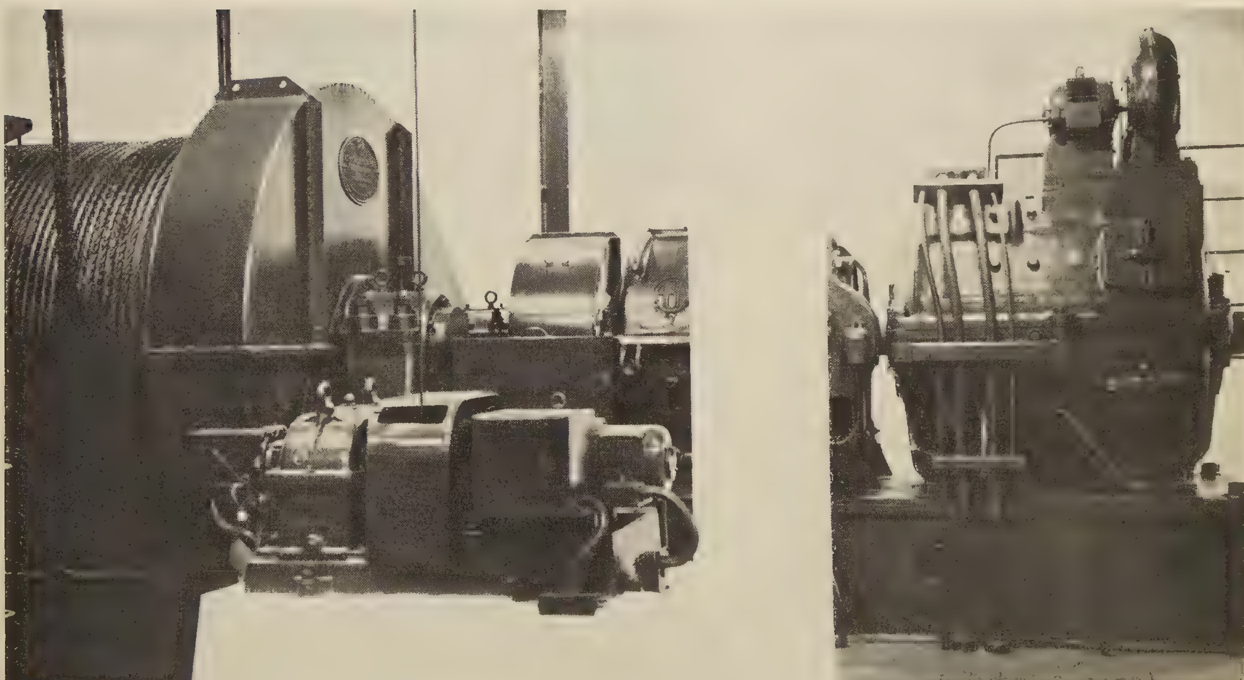


FIG. 6—Skip-hoist winch and stockline recorder

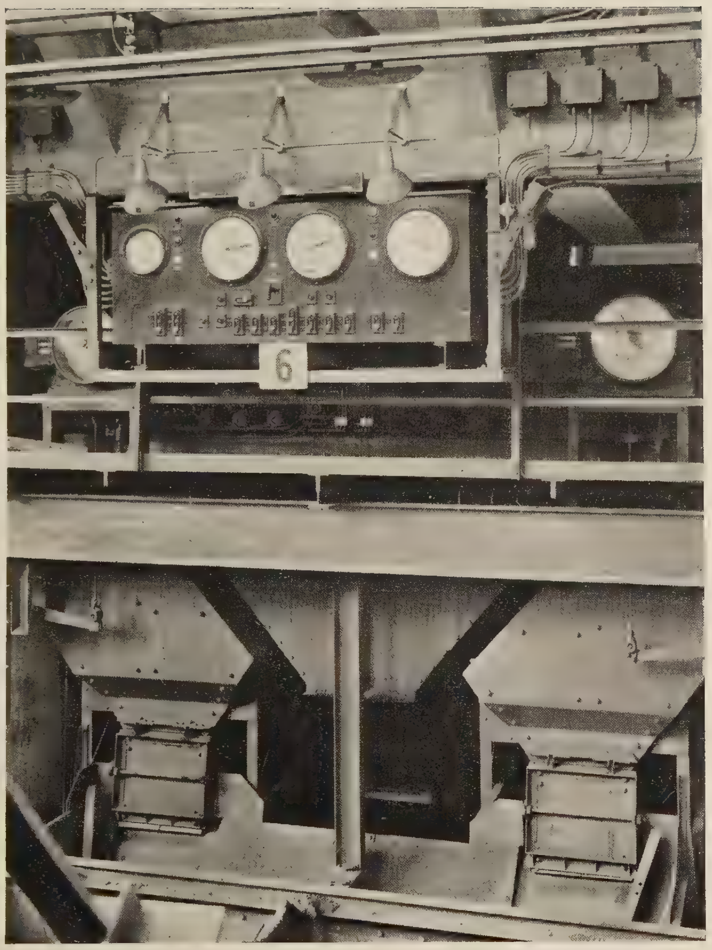


FIG. 7—Automatic coke-weighing and measuring equipment
(Above : Control panel ; in rear : Coke Screens)

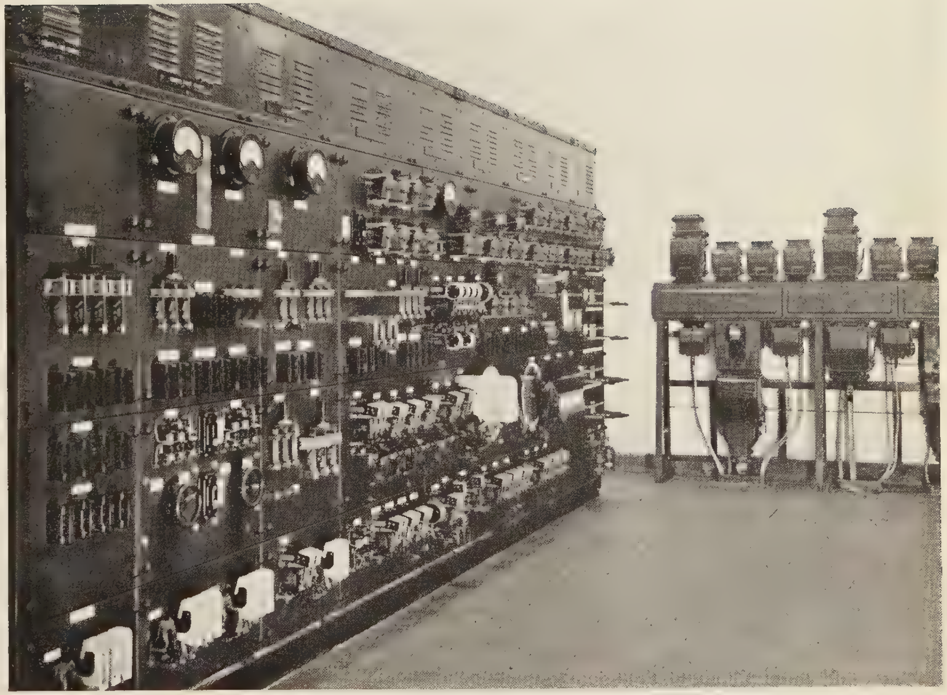
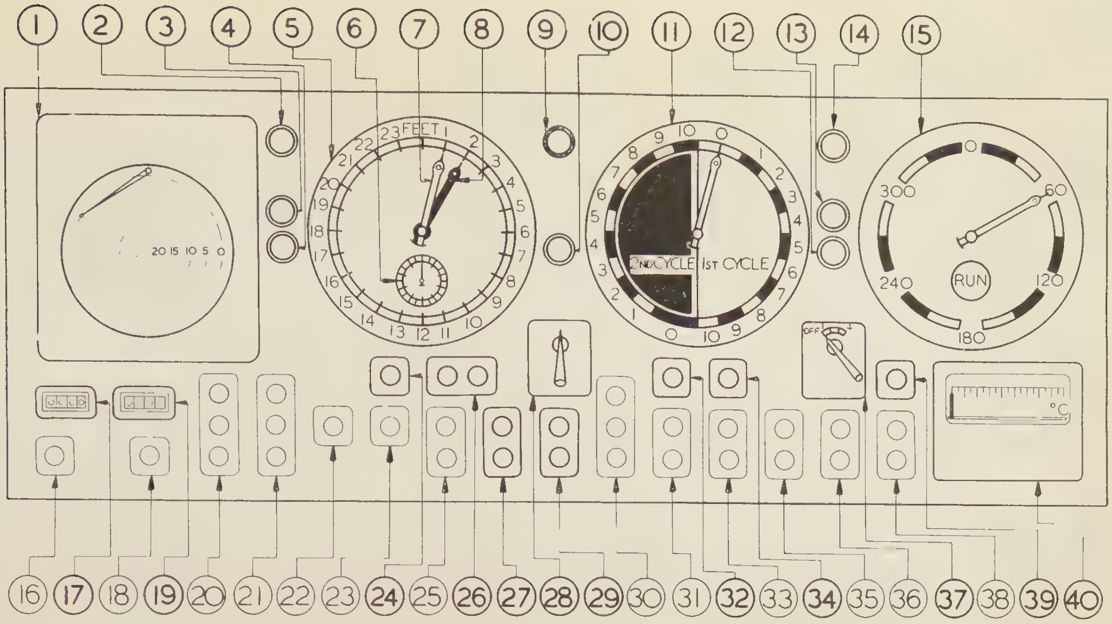


FIG. 8—Sequencing panels for charging control



MOUNTED ON THE CHARGING CONTROL PANEL ARE THE FOLLOWING CONTROLS AND INDICATORS:
(ALL PUSH BUTTONS SHOWN IN FAINT LINE ARE FOR USE WHEN THE FURNACE IS ON HAND CONTROL.)

(1) SOUTH STOCK LEVEL RECORDER. CHART OF BURDEN MOVEMENT AND DUMPS OF LARGE BELL.
(2) INDICATOR LIGHT–SOUTH SKIP IN PIT.
(3) INDICATOR LIGHT–SMALL BELL OPEN.
(4) INDICATOR LIGHT–SMALL BELL CLOSED.
(5) STOCK LEVEL INDICATOR AND VISUALISER.
(6) VISUALISER: MANNER IN WHICH BURDEN DESCENDS IS SHOWN BY THE REGULAR OR ERRATIC MOVEMENT OF THE POINTER
(7) SOUTH STOCKLINE POINTER: INDICATES BURDEN LEVEL IN FEET.
(8) NORTH STOCKLINE POINTER: INDICATES BURDEN LEVEL IN FEET
(9) INDICATOR LIGHT–COKE CHARGE. WHEN LIT, SKIP IS DUE TO RECEIVE A COKE CHARGE.
(10) INDICATOR LIGHT–STOP FILLING (OPERATED FROM FURNACE CONTROL ROOM.)
(11) ROUND INDICATOR: SHOWS PROGRESSIVELY THE NUMBER OF SKIPS OF EACH HALF ROUND, THAT HAVE BEEN PLACED ON THE LARGE BELL
(12) INDICATOR LIGHT: LARGE BELL CLOSED.
(13) INDICATOR LIGHT: LARGE BELL OPEN.
(14) INDICATOR LIGHT: NORTH SKIP IN PIT.
(15) DISTRIBUTOR INDICATOR SHOWS POSITION OF DISTRIBUTOR WITH LAMP LIT WHEN RUNNING.
(16) PUSH BUTTON–SOUTH SKIP WATER. MANUAL CHARGE OF WATER TO SKIP.
(17) TOTAL COKE SKIP COUNTER.
(18) PUSH BUTTON–NORTH SKIP WATER (SEE (16))
(19) TOTAL SKIP COUNTER.
(20) PUSH BUTTONS–SOUTH SCREEN (COKE TO HOPPER)
(21) PUSH BUTTONS–NORTH SCREEN (COKE TO HOPPER)
(22) PUSH BUTTON–SOUTH COKE CHARGE (HOPPER TO SKIP)
(23) PUSH BUTTON–NORTH COKE CHARGE (HOPPER TO SKIP)
(24) PUSH BUTTON–CYCLE RESET. DUMPS LARGE BELL AND RE-STARTS THE NEXT CYCLE.
(25) PUSH BUTTONS–NORTH AND SOUTH SKIPS. INITIATES ASCENT OF SKIP.
(26) PUSH BUTTONS–COKE CHARGE: INITIATES AUTOMATIC FILLING OF SKIP WITH A PREDETERMINED VOLUME OR WEIGHT OF COKE.
(27) PUSH BUTTON–STARTS AND STOPS SKIP DURING RUN WITHOUT INTERRUPTING AUTOMATIC SEQUENCE.
(28) STARTING SWITCH–INITIATES ASCENT OF SKIP WITH WHICH IS INTERLOCKED ROTATION OF DISTRIBUTOR AND DUMPING OF SMALL BELL.
(29) PUSH BUTTONS–EMERGENCY STOP AND RESET OF ALL CHARGING EQUIPMENT.
(30) PUSH BUTTONS–DISTRIBUTOR POSITIONS. (DISTRIBUTOR ANGLE IS PRESELECTED AND MOVEMENT INITIATED BY DEPRESSING RUN BUTTON)
(31) PUSH BUTTONS–SMALL BELL OPEN AND CLOSE.
(32) PUSH BUTTON–EXTRA COKE: ALLOWS REPLACEMENT OF AN ORE CHARGE WITH A COKE CHARGE. WHEN USED IN CONJUNCTION WITH (34) AN ADDITIONAL COKE CHARGE IS FED TO THE FURNACE. I.E. THE COKE CHARGE IS NOT RECORDED ON (11).
(33) PUSH BUTTONS–BELL SELECTOR. (LARGE OR SMALL BELL.)
(34) PUSH BUTTON–EXTRA LOAD: ALLOWS EXTRA LOAD TO BE CHARGED WITHOUT INTERFERING WITH PRESELECTED SEQUENCE I.E. EXTRA LOADS ARE NOT AUTOMATICALLY RECORDED ON (11).
(35) PUSH BUTTONS–SOUTH STOCKLINE RAISE AND LOWER TEST ROD.
(36) PUSH BUTTONS–NORTH STOCKLINE RAISE AND LOWER TEST ROD.
(37) FOUR-POSITION WATER SELECTOR SWITCH (ALLOWS TIMED DISCHARGE OF WATER TO SKIPS):
1–OFF
2–TIMED VOLUME OF WATER TO COKE SKIPS.
3–TIMED VOLUME OF WATER TO ORE SKIPS.
4–TIMED VOLUME OF WATER TO ALL SKIPS.
(38) PUSH BUTTONS–LARGE BELL OPEN AND CLOSE.
(39) PUSH BUTTON–EXTRA WATER (WHEN REQUIRED.)
(40) TOP-TEMPERATURE INDICATOR.

Fig. 9—Details of charging-control panel

[Brown

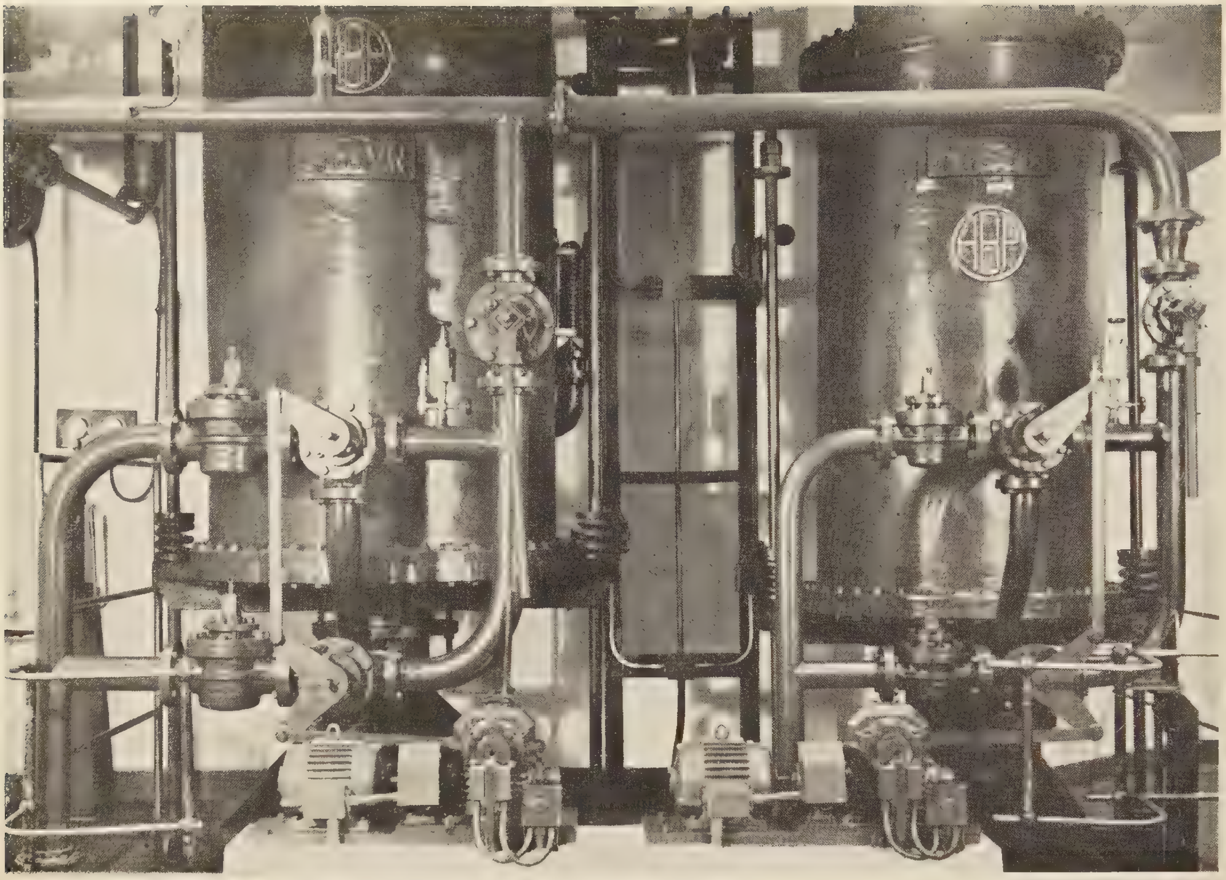


FIG. 10—Pneumatic bell hoists

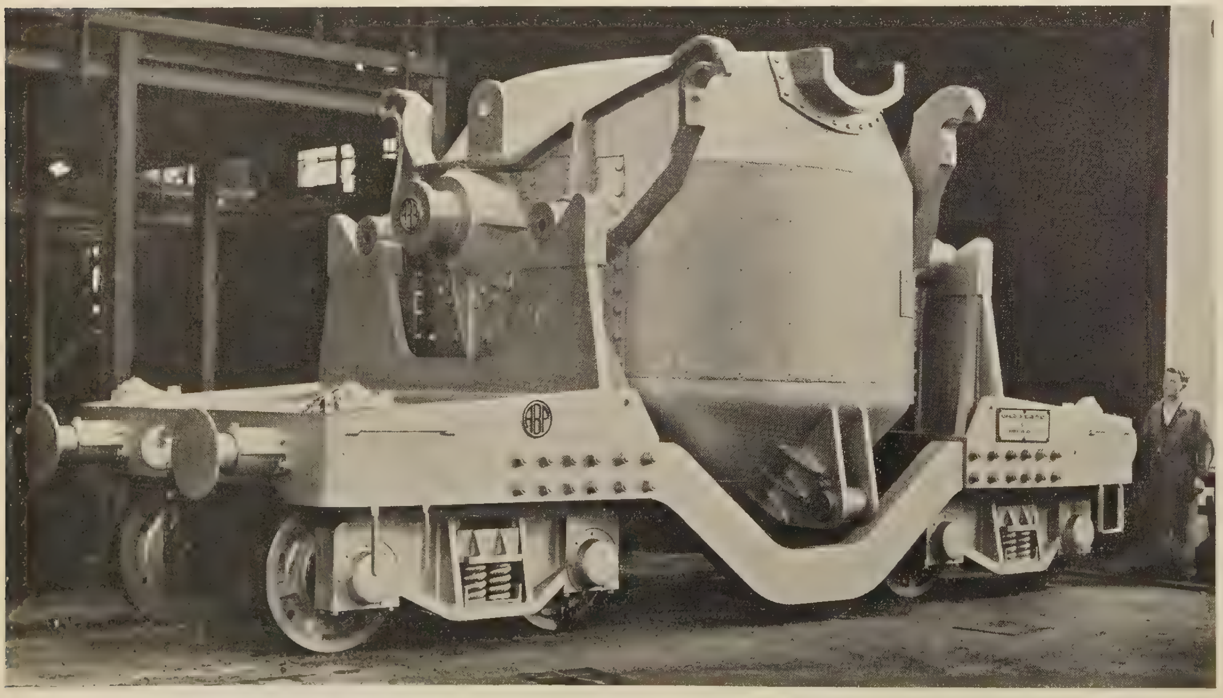


FIG. 11—75-ton Kling-type hot-metal ladle

5 columns, as no margin would remain in the event of one being damaged by a break-out. An asymmetrical arrangement employing more than 5 but less than 10 columns in such a furnace had little to commend it. With hearth diameters of 20 feet and upwards, we enter the field of 12, 14, or more tuyeres and then to employ 6, 7, &c., columns becomes a practical and desirable proposition. Furthermore very heavy H-section columns are now being designed with a profile that obscures less of the bosh wall than did the cast-iron or compound steel column. Hence the bosh walls truly have an air of greater accessibility.

In the realm of furnace cooling there are no changes. Copper plates are invariably used in the bosh and tuyere jackets, with the same or cigar-shaped coolers in the stack. The extent of stack cooling varies, but an interesting point is that certain of the furnaces with intensive stack cooling show excellent coke-consumption figures. This is not proffered as cause and effect nor need extensive cooling be desirable but, on the other hand, it is evidence that little or no detriment results from liberal cooling. Hearth cooling alone gives rise to contoversy ; internal water-cooled staves, external sprays, each and all have on occasions proved vulnerable to break-outs. One conclusion alone is inevitable : The hearth jacket, however well it may be cooled, offers but little resistance to molten metal when once the brickwork has been penetrated.

Refractory linings show very little change, though satisfaction with the existing state of affairs rests only with the more fortunate. There are certain classes of iron produced in this country which show little respect for even the best-laid hearths. The sufferers are turning to carbon blocks and there will be much experimenting with size and shape, method of jointing, &c., before the most self-confident will venture a final recommendation.

Of the two furnaces giving the highest total production figures in the last 10 years, one hearth was laid with dipped, very close, fireclay joints, and the other with wider, buttered, high-temperature cement joints. Both methods of construction have proved equally susceptible to break-outs at other plants and this is the type of tantalizing evidence on which the student of form has to make his choice. A guaranteed hearth construction is surely something which will long elude the designer and the refractory expert.

Four gas offtakes are invariably used and the system, popularized by McKee, of collecting these into a single downcomer has gained much favour. Constructionally, it has the advantage of symmetry and offers a very convenient mode of entry for the gas into the dustcatcher. Primary dustcatchers have been improved in design and the non-turbulent passage of the gas makes the modern appliance very effective. The introduction of a secondary dustcatcher depends upon what advantage is to be obtained in extracting the maximum volume of dust in the dry state. It may suffice to let the dust which passes the primary dustcatcher be handled in the gas-cleaning plant, but when secondary dustcatchers are used these are generally of the "straight-through" Vortex type. All self-respecting modern plants will discharge dust through pug mills so that the nuisance and danger of a dust-laden atmosphere is abolished.

All new furnaces are normally isolated from the gas system by valves, though sometimes provision is also made for a water-seal as an alternative. Most of the new furnaces in this country, as in the U.S.A., use the thermal-expansion goggle valve.

In planning a new installation of hot-blast stoves, cognisance has to be taken of the fact that, whereas straight-line blast temperatures of 1500° F. may—as they occasionally are—be required in practice, the British basic furnace is usually content with 1000° F. To meet this combination, designers offer three stoves per furnace which when all are working provide the higher temperature or with only two working suffice for the lower figure. The compromise meets both extremes and provides also an element of reserve without undue capital outlay. Changes since the 1930–1940 era are confined to the stove filling. Zoned checker work, which usually placed the maximum brick mass where it did the least work, is being ousted by fillings of uniform cross-section. An innovation with easily understood advantages is the stove lining, of which the internal profile, in cross-section, forms a polygon or multi-sided figure, designed to do away with the indiscriminate cutting and weak construction which arose from fitting the checker pattern into a circular space. (*See* Fig. 12.)

Amongst furnace auxiliaries, there are certain refinements which were comparatively new to the 1930–1940 period which today cannot be regarded as less than essential to the modern furnace. Foremost amongst these are :

(*a*) The passenger lift giving access to the furnace-top platform.

(*b*) The built-in out-rigger providing facilities for readily dismantling the furnace-top equipment and lowering bells, hoppers, &c., to ground level.

(*c*) Remote-controlled electric clay guns.

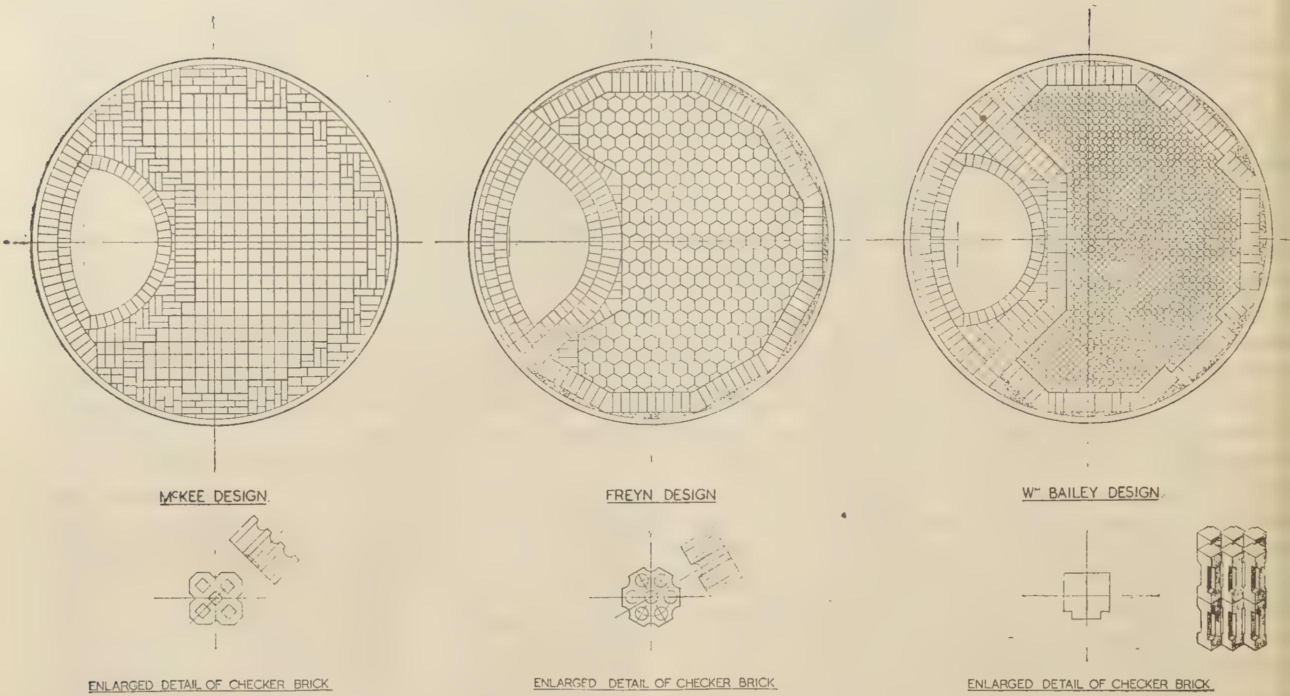


FIG. 12—Sections of various hot-blast stoves

(*d*) Automatic regulation of "straight-line" blast temperatures.

(*e*) Continuous recording of the stock level with visual indication of how the stock descends.

(*f*) The pugging or conditioning of flue dust.

(*g*) The cast house, giving protection against weather, and the cast-house crane, giving lifting facilities over a vital area.

The subject of gas cleaning is wide enough to call for a paper devoted to that topic alone. There are nevertheless some general comments that should find place in the present review. Opinion is no longer divided on the advantages of cleaning all the gas to a high degree. There are several methods of so doing, but it is probable that the wet electric precipitation plant will now be almost the unanimous choice where freedom of selection is not restricted by any existing circumstances. One feature, common to all new plants and which will, wherever possible, be sought in all reconstructions, is that the gas-cleaning plant should stand in close proximity to the dustcatchers, so avoiding all horizontal dirty-gas mains with the dust-handling problem that these entail. Hot, dirty gas and hot, dry flue dust are two evils that wage continual war on plant maintenance In a truly modern plant these will be converted into their more tractable forms of cold clean gas, pugged dust, or gas-cleaning-plant effluent, at the earliest opportunity.

The increasing size of blast-furnaces and the greater tonnages produced have brought about very distinct changes in the method of handling the products. The once ubiquitous sand beds which formed a feature of all furnace plants will no longer prove practicable for the furnaces of the future. At several plants of the 1930–1940 era, sand beds had already disappeared and iron that was not sent to the melting shop in ladles was poured over pig-casting machines. There are probably few mechanical devices which perform a more arduous task than the pig machine; and their advent should not foster the delusion that the disposal of hot metal no longer demands care and consideration. A machine which daily brings into contact 500 tons of hot metal and 1000 tons of water can well be expected to need proper care and attention.

The selection of hot-metal ladle equipment will largely be a matter of circumstance, though certain principles are already evident. The simple form of open pot is giving way to pots shaped to give some degree of heat conservation. Extremes in this direction must be avoided where interference would be caused with easy filling and pouring. Unusually long hauls or other reasons for holding metal for long periods in ladles, may necessitate the use of large mixer-type ladles from which the metal has to be transferred to smaller ladles in the melting shop. But in all

other cases opinion seems to favour ladles of a size that can be handled by the steelworks cranes and need no special arrangements of traffic and railroads. The 75-ton ladle (Fig. 12) is found in America to provide a happy compromise and the same is likely to prove equally popular in this country.

As the champion slag-producing country of the world, we must surely seek the most efficient method of handling this by-product. The large steam or compressed-air, tilted slag ladle was gaining favour at our modern pre-war plants when progress was arrested by the altered conditions arising from the black-out requirements. The problem will now reassert itself and designs for new plants will doubtless be based on the use of pots of at least 330 cu. ft. (20 tons) capacity.

Carriages for both hot-metal and slag ladles are at present fitted with roller bearings, and in a recent installation these are fitted as individual wheel bearings rather than as axle journal bearings. This provides the necessary differential feature when negotiating curves, thus lightening the load on locomotives and drawbars.

In conclusion let it be remarked how costs of production must mainly depend upon two factors. First, the economy with which the metallurgical process can be carried out, reflecting the skill with which the furnace is handled, and measured in terms of coke consumption. Secondly, the economy with which the formidable tonnages of materials can be assembled and charged in continuous and precise rotation, blast supplied at correct temperature and pressure, and the products, iron, slag, and gas, effectively handled—this is the field where engineering ingenuity alone can be the factor responsible for results. New plants must be planned to profit by all the known methods of economizing in handling vast tonnages; they must also make use of the most reliable equipment to ensure continuity of operation. The most skilful operation of the furnace will be sorely frustrated if lack of facilities, unreliability, and a badly planned plant are allowed to sabotage the cost accounts. The standard of engineering achievement already reached is highly commendable, but there remains ample scope for improvement, especially in those things where the rigorous conditions of blast-furnace work present exceptional problems.

Part II—A COMMENTARY ON CURRENT FURNACE ENGINEERING*

By I. S. Scott-Maxwell, A.M.I.E.E., A.M.I.Mech.E.†

Introduction

During the last 25 years engineering technique as applied to blast-furnace plants has improved tremendously. Every detail around a furnace plant now receives more attention, so that where the layout is correct, increasing success is ensured. Also, the many meetings, discussions, and technical papers which now take place greatly improve the standard of knowledge of the furnace operator. Even if some of these men have to manage old plants, they generally have up-to-date ideas. We are, therefore, well equipped for the major task now before us. There is much new building and modernizing of old plants to be done. The success of these plants will be very much the responsibility of the engineers and designers. The blast-furnace industry, together with plant manufacturers, can usefully co-operate to give Great Britain the highest standard of plant and performance in the world.

Layout and Economic Operation

The economic aspect must be kept prominently in mind when considering any new development. The cost of operating the final plant is of paramount importance. Unfortunately we are, in most cases, forced to scrutinize carefully the capital cost of the new plant. Nevertheless, we must strive at all times for the best design, and the standard of efficiency must be high.

In the particular case of iron and steel works, the main problem is handling the vast bulk of raw materials, internal products, and by-products, as well as the iron and slag. Methods must be devised and continuously improved for

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† British Iron and Steel Federation.

cheap handling, otherwise even the best operator is continuously saddled with heavy running costs.

As an illustration, the materials required for a plant making 450,000 tons of basic iron per year, when using foreign ore (case *A*, coke consumption $16\frac{1}{2}$ cwt./ton pig) and when using home ore (case *B*, coke consumption, 21 cwt./ton pig), are approximately as follows:

	Case *A*.		Case *B*.	
	Cwt./ton of iron.	Tons/year	Cwt./ton of iron	Tons/year.
Coal	...	595,000	...	756,000
Ore	36	836,000	56	1,230,000
Limestone	6	135,000	10	225,000
Iron	...	450,000	...	450,000
Slag	10	225,000	$22\frac{1}{2}$	505,000
Total	...	2,241,000		3,166,000

These figures do not include by-products or internal works traffic. When one considers that the total pig-iron requirements for Great Britain, under the new programme, will be about 9 million tons, it will be seen that the volume of traffic to be handled is enormous, about 20 times the above figures.

We must, therefore, have modern handling plants at the docks, adequate mining machinery, and haulage by large-capacity wagons. At the works we must think in terms of gravity-fed sidings, large-capacity mechanical tipplers, conveyor belts, bridge transporters, and ample stockyards. The assembly costs at the high line must be reduced to an absolute minimum.

Internal works traffic should also be at a minimum, the number of locomotives as few as possible, and the railway tracks simple and well laid. To give freedom of movement there should be no "dead-end" tracks. Flue dust from the pug mills, as well as coke breeze from the furnace screens, should go by belt to the sinter plant. Washer slurry generally cannot be vacuum-filtered to a moisture content lower than 18–20% with present plant. This makes it difficult to handle without previous dumping on the ground and relifting. Better filter equipment should therefore be designed or a drying stage incorporated, using the waste heat from the sinter plant or boiler chimneys so that this material can be handled direct by belt.

Adequate road access is a necessity on a large plant. Such roadways should be available to as many parts of the plant as possible. Maintenance and production departments will find this provision extremely helpful. Portable welding machines, compressors, winches, &c., can be taken about quickly, and spare gears, motors, wearing plates, oxy-acetylene burning equipment, &c., can likewise be transported without having to be hauled or man-handled over railway lines.

It may be said that these are all details; so they are, but although the blast-furnace itself is large, it is essential that the details be correct. Unless such matters are considered, the lowest possible costs will never be attained.

Finally, any development of a plant should provide space for expansion and additions at some future date. This is not always easy and sometimes the prevailing conditions are not encouraging. Nevertheless, the factor is of such importance that first consideration should be given to it at all times.

Material Handling and Preparation

The modern dock unloader, ore bridge, conveyor belt, dragline scraper, and excavator are all well-tried and tested pieces of equipment. They handle materials well and quickly with low cost and maintenance, provided that they are operating at or near the designed capacity. The same can be said of ore-bedding and ore-preparation plants generally. The manufacturers, however, do not always make their machines sufficiently robust. It is realized that the iron and steel industry must have heavy equipment, but sometimes there are weak links which bring machines to a standstill. We all know of such troubles—an unsatisfactory limit-switch or gear-box, a troublesome bearing, or a weak shaft.

With regard to crushing machinery, no manufacturer has yet designed a secondary crusher which will deal with soft or wet ore (moisture about 18–20%). Some thought should be given to this, as it is a vital link in the preparation of British ores for smelting. It may be that the only solution is a drying stage, but this, of course, requires fuel and therefore incurs additional operating cost. On foreign-ore plants we have to deal with a very wide range of ores with different smelting characteristics, and it is necessary that these ores should be crushed to different sizes, varying from 3 in. down to 1 in. Present crushers have cumbersome arrangements for altering the setting, this operation often taking some hours. As British plants must be flexible enough to handle a number of ores in quick succession, we require a secondary crusher to handle dry ore, often of a "stoney" nature, with a push-button control to alter the setting. As it is not always easy to divert or hold up large quantities of material, such a piece of equipment would be extremely useful.

At this stage some mention might be made of the handling of scrap on a blast-furnace plant. The difficulties that were experienced during the war

are well known, and as there will always be certain types of scrap available for the blast-furnace it is suggested that designers should give this more attention.

A furnace making 3,000–4,000 tons per week should be able to consume about 500 tons of properly prepared scrap per week. It should not be difficult to incorporate in the general layout a proper scrap-preparation yard with a few simple machines such as shears and presses. It is also necessary—and this is the difficult feature—to provide mechanical equipment to convey the prepared scrap into the skips, as it is essential that scrap be charged regularly. Erratic charging of scrap will upset the hearth temperature and therefore the iron quality. The advantages gained in fuel saving, keeping the furnace walls clean, reduced costs, and higher output, would fully justify the expense of the equipment.

With regard to the relation between the ore stockyard, screens, and high line, consideration must be given to the fact that if the furnace is charged in "sized layers," higher output and smoother operation will be obtained. Present-day knowledge indicates that two or three size-groups might be sufficient. The problem of achieving this is different on a plant using a variety of imported ores, compared with one using bedded home ore.

Home ores vary considerably in chemical analysis, but have a fairly narrow range of reducibility, that is to say, the rate of smelting of the different ores is very similar. This, therefore, justifies the use and expense of a bedding plant and allows a constant degree of crushing for all grades of ore. It follows that the bedded material can be separated easily into two or three sizes for charging to the furnace. Further, a minimum number of furnace bunkers would be required on such a plant.

Individual imported ores, however, are reasonably constant in chemical analysis, but the different types have a very wide range of reducibility. The expense of a bedding plant may therefore not be necessary or justified, but a wide degree of crushing must be available to offset the differences in smelting rates. On this basis we may be in the awkward position of having to charge to the furnace two or three sized groups of each individual ore. If six or seven ores are used, which is quite common, a very large and impracticable number of furnace bunkers would be necessary.

We are therefore forced to the conclusion that for the most efficient operation only two or three ypes of imported ore should be used on one plant, and these should not be of widely different reducibility. These ores could then be mixed in the correct proportions after crushing and separated into the required sizes before charging. On this basis it might mean that two stockyards would be necessary, one for raw ore and one for prepared ore. It is suggested, however, that as much flexibility as possible must be provided for, because of the varying conditions in the foreign-ore market. Therefore a larger number of high-line bunkers are required than would be necessary in a home-ore plant. It can also be seen that some simple form of mixing plant requires to be designed and incorporated in the layout.

On both types of plant it is suggested that, to reduce the fines going to the furnace, the ores should be stocked before and not after screening. Screening should be the last operation immediately before the ores are put in the furnace bunkers. Sinter for current consumption should not normally go through the stockyard to the high line, although provision must be made for stocking excess production.

As an example of faulty layout, one plant in this country using imported ores has the stockyard in such a position that the ores from it can go only to the furnace bins. This means that any fines created in the stockyard must go to the furnace. Also, if size charging were to be adopted it would be necessary to stock separate piles of each size of each ore, thereby greatly reducing the overall capacity of the stockyard.

Figs. 1, 2, and 3 show schematically what should be aimed at. The layouts will naturally vary according to site conditions and the type of ores being used. No one scheme can be standardized. It should be clearly understood, however, that the final operating conditions required are the despatch of graded screened material to the furnace bunkers.

The high-line bunkers should not be regarded as stocking space, but they should be of sufficient capacity for about 24 hours' operation without refilling. Using bedded home ores, only about 6 bins per furnace would be necessary, but on a foreign-ore plant 10 or 12 may be required. These bins should have provision for heating, to prevent the ore from freezing during periods of frost. If they are made of steel this can be conveniently done by hot blast.

Much development has taken place with regard to electrical equipment and charging control. Practically everything is now catered for, and one man per shift can handle all the materials charged to the furnace. The operator still awaits, however, a reliable and accurate instrument

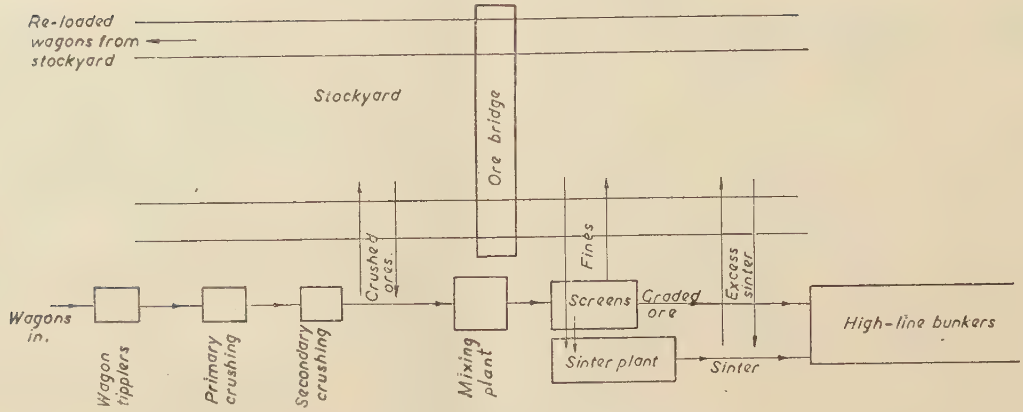
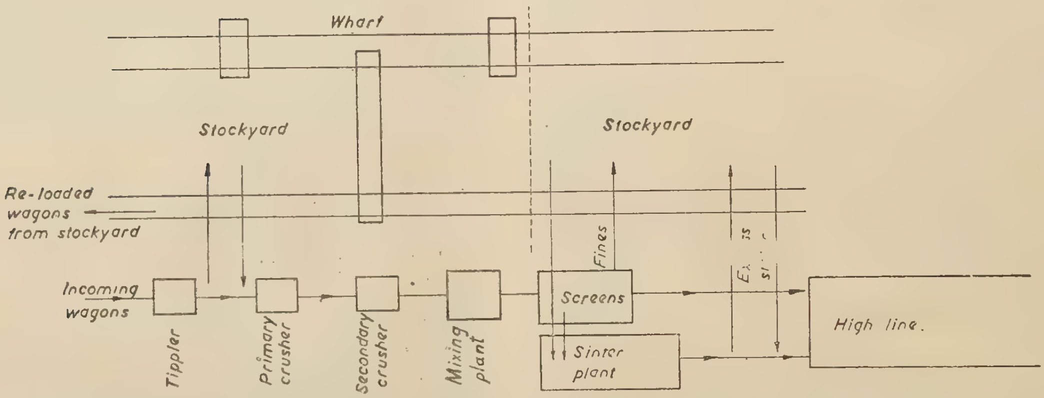
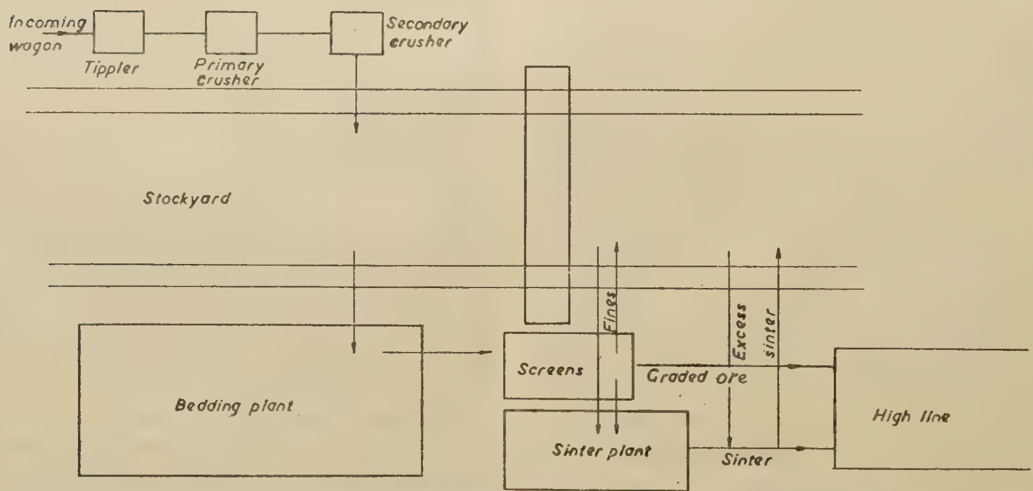


Fig. 1—Schematic layout of flow of materials to plant by wagon : Foreign ore



Note—If riverside stockyard is remote from plant, a separate, smaller stockyard is required for fines and sinter.

Fig. 2—Schematic layout for riverside plant : Foreign ore



Note—Depending on the ores being used, it may be necessary to take some fines out before bedding, and also provide a drying stage before sintering.

Fig. 3—Schematic layout for bedded material : Home ore

for recording the weight of ore charged to the furnace. This is difficult under the conditions prevailing and is complicated by the fact that more than one type of ore is usually put into the scale-car hopper at the same time.

On any plant with more than two furnaces some arrangement of loop-line should be provided, so that in the event of a scale car breaking down it can be taken out of service quickly and a spare put in. If this is not provided a delay to furnace charging occurs, either because an attempt is made to repair the car on the spot or because some confusion takes place when the cars and drivers are shuffled about on a straight track.

Electric skip hoists and air-operated bell-gear are all satisfactory and with modern equipment give very little trouble. Dustcatchers, &c., should be as remote as possible from the electrical-control panels, although these stand up extremely well under the most adverse conditions.

Another point which might be mentioned at this stage is the skip tipping angle. It is most important that this should be maintained at the correct figure, otherwise an alteration in the distribution will occur, owing to the varying conditions of segregation. Unfortunately, rope stretch alters this angle. The taking-up of rope stretch means a delay in furnace production, and it is important that designers should develop a more convenient arrangement so that it can be done in a matter of minutes. It is suggested that some form of split winch drum might prove satisfactory. It cannot be done by adjusting the electrical limit-switch when the ropes from two skips wind on a single drum.

Of all pieces of charging equipment the distributor is the most important. It must run correctly or furnace operation will suffer. In this respect the pointer instrument will ensure a continual check on the distribution position. The older type of instrument with illuminated figures suffered from the disadvantage of the lamps burning out.

Furnace Stack and Top Gear

Distribution by the McKee top as at present designed is reasonably satisfactory and the equipment is very widely used. It is realized that the present McKee top does not give perfect distribution. Something better is required. With present equipment it is considered desirable that the small bell hopper should be made to last the life of the small bell. Furthermore, the design should permit these parts to be taken out together or cut away and replaced from below without having to dismantle the entire distributor. The large bell and hopper should certainly be designed to last the furnace campaign, assuming, of course, that they get proper treatment and are not at any time unduly overheated. It is considered that major top repairs of this nature should be done only at relining periods.

With regard to the stack as at present designed, there is no doubt that on the larger furnaces now being built the small number of columns permissible make for a clean, open appearance. Stack and bosh cooling is not altogether satisfactory, and it is suggested that on foreign-ore furnaces this should be increased in the region of the bosh parallel and at the bottom of the stack. Cooling higher up the stack does not seem so necessary. Some consideration might also be given to the German design of spray-cooled, plated, and carbon-lined bosh and hearth. This eliminates all internal coolers, uneven wear of lining, and external pipes. If stave hearth coolers are used, then much of the circulation should be in parallel, particularly around the tap-hole and slag notches. This prevents any complete water stoppage if a blockage occurs.

A future development in furnace practice will probably be a furnace designed for a high top pressure, that is, 10 lb./sq. in. or higher. Preliminary researches in the laboratory indicate that the idea is sound. It is claimed that the reduced gas velocity in the stack owing to increased density eliminates channelling and irregular stock descent. The economies of such a practice are open to argument, and in an effort to offset the higher blowing costs it is hoped that some power recovery may be obtained by using a turbine in the high-pressure gas stream. The main difficulty at the moment, however, is one of engineering design. On such a practice no gas leaks are permissible, otherwise the smallest hole is soon made very large by the dust in the gas. It is suggested that operators and designers should give this problem some attention now, as it is thought that the idea will develop considerably.

Around the hearth and bosh region the following points might be mentioned :

(1) Provision for the adjustment of the blowpipe level to enable tuyeres and blowing coolers to be kept correctly aligned.

(2) Improved design of the "swan-neck" and its fittings, to permit quick and easy tuyere changing.

(3) A fitting to allow the use of a Pitôt tube in each blowpipe would be of great advantage in giving an indication of the air velocity at each tuyere.

(4) The layout of iron and slag runners in the cast house should be arranged to give minimum

length and ample fall. Whenever possible, particularly on the high slag volumes, the angular distance between the tap-hole and the slag notch should be as large as possible. This will reduce the severe erosion and wear which takes place on this section of the hearth owing to the action of the iron and slag in the furnace.

Auxiliaries

When considering stove design it should be remembered that some types of foreign ore require straight-line temperatures in the region of 1200–1400° F., whereas home-ore burdens are usually smelted at 950° F. or less. With increasing ore preparation and faster-moving furnaces these temperatures may, with benefit, be raised still higher. It is therefore important to ensure that there is sufficient stove capacity on a modern plant. A future development in stove equipment might be the provision of metal recuperators. These are used on small furnaces in Sweden and there is a larger installation in the Saar. It would be interesting to know, with the experience that has been gained, what designers have to offer.

Present-day stove fittings, with the exception of the hot-blast valve, are extremely good. The hot-blast valve, which admittedly is subjected to extremely severe conditions, is the most frequent source of trouble. Some improvement in design would be welcomed. As it is necessary to put a furnace off blast to change this valve, more permanent equipment for carrying out the work quickly would be helpful. With the present-day practice of setting-up tackle each time the job has to be done, much time and money are wasted.

Slag and iron ladles are now fitted with roller bearings and are excellent in design. The barrel-type iron ladle of about 70 tons capacity is a convenient size and will take about 30,000–35,000 tons of iron on one lining. Difficulty is sometimes experienced in keeping the top open, and it is thought that a slightly wider opening than that at present provided would be helpful.

The total weight of these ladles when full of metal approaches 140 tons, and even on the best-operated plants they are sometimes derailed. When this occurs it would be helpful if the bogie could be secured to the carriage, so that the whole could be jacked-up together. It is also suggested that less wear on the axle thrust pads and wheel flanges would occur if a roller-type bearing was fitted between the bogie and the carriage, instead of the present steel pad which is difficult to lubricate and gives rise to heavy friction.

The large steam-tipping slag ladles are of great advantage, both to the operator and on the slag hill, where they give a long throw of slag. Every plant should have these, and for an output of 1,000 tons per day from two furnaces, at 12 cwt. of slag, only eight would be required.

Gas-cleaning equipment adjacent to the furnace is excellent as it eliminates the dirty-gas main. This main, being subjected to much temperature variation and requiring internal cleaning, is often a source of considerable maintenance and dust.

A word might be said about boilers. To be up-to-date these must be designed primarily for the main fuel to be used, which will generally be blast-furnace gas. Furthermore, steam pressure should be in the region of 300–550 lb./sq. in., and the total steam heat may be as high as 1650° F.

Each furnace should have its individual turbo-blower, fitted with constant-volume control. Blowing is on many plants a very heavy item of cost. Blast leaks, badly run mains, and inefficient steam generation are often to be found. With modern design, costs may be as low as 3 or 3½*s*. per ton of iron instead of more than double this figure.

Finally, it should be mentioned that a modern plant requires to be properly instrumented for efficient operation. Adequate metering of electricity, gas, steam, and water must be considered in the initial stages in relation to the plant as a whole. It frequently happens that the provision of gas-flow measurement is considered only as an afterthought and then it is not possible to find a sufficiently straight length of gas main to give accurate metering. Proper control of production and costs necessitates proper instrument layout and provision for their maintenance after the plant is running.

BRITISH STANDARDS FOR LIFTING TACKLE

The British Standards Institution has published B.S. Handbook No. 4, a collection of a series of standards for lifting tackle. The first five sections contain the technical provisions of 21 published standards concerning fibre rope, wire rope, chain, and terminal attachments. The last two sections of the Handbook are supplementary and deal with the statutory requirement under the Factories Act applicable to lifting tackle.

In the Introduction by Sir William Stanier, F.R.S., attention is drawn to the responsibilities devolving upon the user of lifting tackle as to maintenance and renewal, and recommendations for ensuring safety are given.

Copies of the Handbook, which is edited by A. L. Haas, I.S.O., M.I.Mech.E., are obtainable, price 12*s*. 6*d*., from the British Standards Institution, Publications Sales Department, 28, Victoria Street, London, S.W.1.

Engineering Problems in the Preparation of Ores for Blast-Furnaces*

By D. C. Hendry, A.M.I.Mech.E.†

SYNOPSIS

This paper outlines difficulties encountered in the crushing, screening, and blending of ores for the blast-furnace, with particular reference to Northamptonshire and Lincolnshire ores, and describes the types of equipment in use for these operations, noting the advantages and disadvantages of each type and the precautions necessary to ensure smooth operation.

A critical examination is made of normal sinter-plant layout and equipment, and suggestions are given for improvements to raise the quality of sinter produced.

Discussion of modern British plants occupies most of the paper, but the review would not be complete without some reference to one of the most modern ore-preparation plants—that of the Hütte Braunschweig, Germany—which is described in some detail.

One necessity which emerges from a comparative study of different plants is a much closer continuous collaboration between designer and operator to ensure that improvements are immediately taken up and defects eradicated.

INTRODUCTION

THE need for adequate preparation of ores has long been recognized by everyone concerned in blast-furnace operation and is true both for foreign and home ores.

It was sufficient in furnace plants of the last century to charge foreign ores as received and sometimes to calcine such ores as were obtained locally. Sizing the raw materials raised no great problem, since home ores were usually hand-gotten and the size was controlled by the weight which could be lifted by hand, as indeed it is today in some cases. Foreign ores were of more or less suitable dimensions for charging directly into the furnaces and created no more serious problem than that of getting them there.

In this country at least, a comfortable state of quiescence existed until the turn of the century. The economic situation, although easy by 1946 standards, was becoming such as to stimulate thought on methods of improving outputs and decreasing costs. Owing to the increasing size of the furnaces and the speeding-up of operation, the day of the manually operated blast-furnace plant was over. We see the handicaps imposed by heavy manual work in some few plants which have survived even to the present time.

The plans recently formulated for the complete modernization of all iron-producing plants amply demonstrate that the age of mechanization has fully arrived, and engineers are faced with a diversity of problems, of which some have been solved and others are in that stage of evolution which will no doubt lead to satisfactory solutions being obtained in time.

In the modern blast-furnace plant the prime conditions which must be fulfilled are to produce the maximum tonnage of iron of the most regular composition for prolonged periods and at the least possible cost. To do so it is necessary to provide and prepare the raw materials in a manner designed to maintain the utmost regularity. In this respect, iron ores, perhaps because of their widely varying physical and chemical characteristics, provide the engineer with many problems. These problems are accentuated by the necessity to reduce the consumption of the most costly necessity in the furnace, namely, coke, to the very minimum everywhere.

This paper deals with some of the ore-preparation problems which have become increasingly important with the development of blast-furnaces. The first was created by mechanization in the ore quarries of this country, with the result that large lumps of ore are sent to the furnace plants and calcining clamps. Imported foreign ores are less usually supplied containing large lumps, but are rather in the condition of containing too many fines.

The essence of the problems is contained in the two conditions mentioned, namely large ore and fine ore, both requiring treatment but naturally differing in kind, and it is proposed to deal with them only. As the calcining of ore has only a limited field of application nowadays and raises no special problems, it can be ignored. Other

* Received 5th December, 1946.

† Messrs. Stewarts and Lloyds, Ltd., Corby.

methods of treating ores are gradually being developed which will largely supplant this process in due course.

Ore Preparation

Crushing

The large size of the ore coming from the quarries entails crushing, and the amount of crushing necessary is determined by the reducibility of the ores in the furnace, or rather, by the particular ore which is most difficult to reduce. The idea is generally accepted today that it is essential to crush down to about $2\frac{1}{2}$–3-in. cube, and to do so a two-stage crushing process is necessary. Much fines are produced in crushing, additional to the natural fines produced in the quarrying operations.

It is realized that some crushing installations consist only of a primary crusher producing ore of 6–7-in. cube, but there is ample evidence to show that many of the home ores must be ground down to a much smaller size than this.

Both lumpy and fine ore have been, and in some installations still are, passed together through the crusher, but with wet, sticky conditions there is a strong tendency for plugging of the crusher to occur, although this is less marked in the two-roll crusher than with other types.

The wetness of the ore determines to some extent the method of feeding it into the primary crusher, and as most home ores from open quarries are really wet and sticky, according to the weather conditions, it is essential that preliminary rough screening should be carried out before the lumpy ores are fed into the crusher, whether it be of the roll or the jaw-crushing type. In any case this preliminary screening or scalping relieves the crusher of an unnecessary load and avoids the production of further ore fines. This applies equally to dry ores from mines or to quarried ores which may be wet. The screening is usually accomplished by a grizzly screen of driven rolls.

The size scalped out ahead of the primary crusher should naturally not exceed the maximum size determined for the final product, *i.e.*, approximately $2\frac{1}{2}$–3-in. cubes with secondary crushing, or larger if only primary crushing is being carried out, when the crushed material may be 6–8 in. cube in dimension.

Some examples of ore-feeding arrangements are shown in Figs. 1, 2, and 3. The applications in all cases are to two-roll crushers. Very high rates of throughput can be obtained by such arrangements, and at the works with which

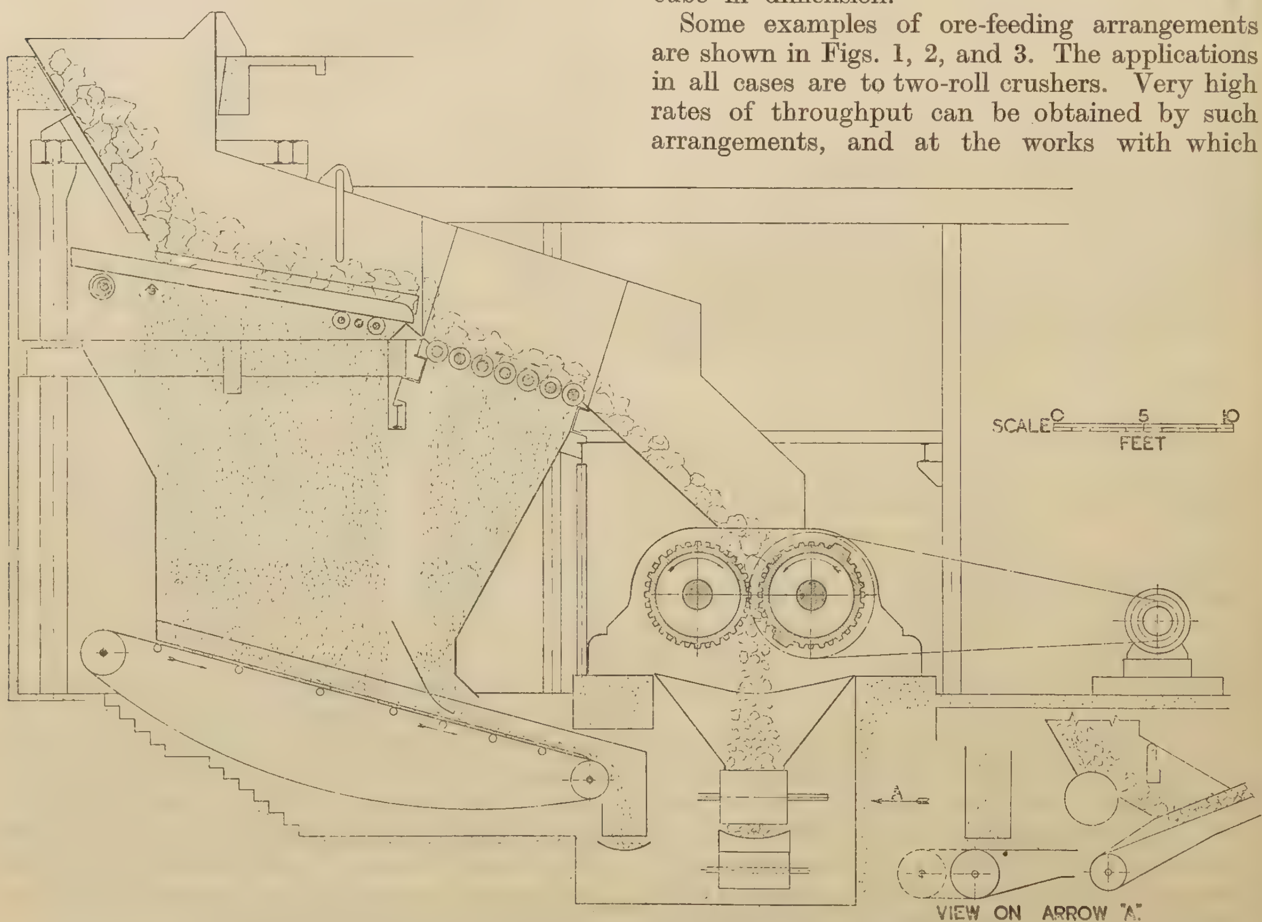


Fig. 1—Primary crushing plant: Old ore-preparation plant, Messrs. Stewarts and Lloyds, Ltd., Corby

to the conveyor belts receiving these materials when they fall on to them is essential. It must be borne in mind that pieces of ore of 6 or 7-in. cube are discharged from crushing rolls with great velocity, enough to damage the belts seriously unless protection is provided. Scalped ore which drops from a considerable height can also damage the belts, and again some protection is necessary to reduce shock and avoid harm. The scalped ore

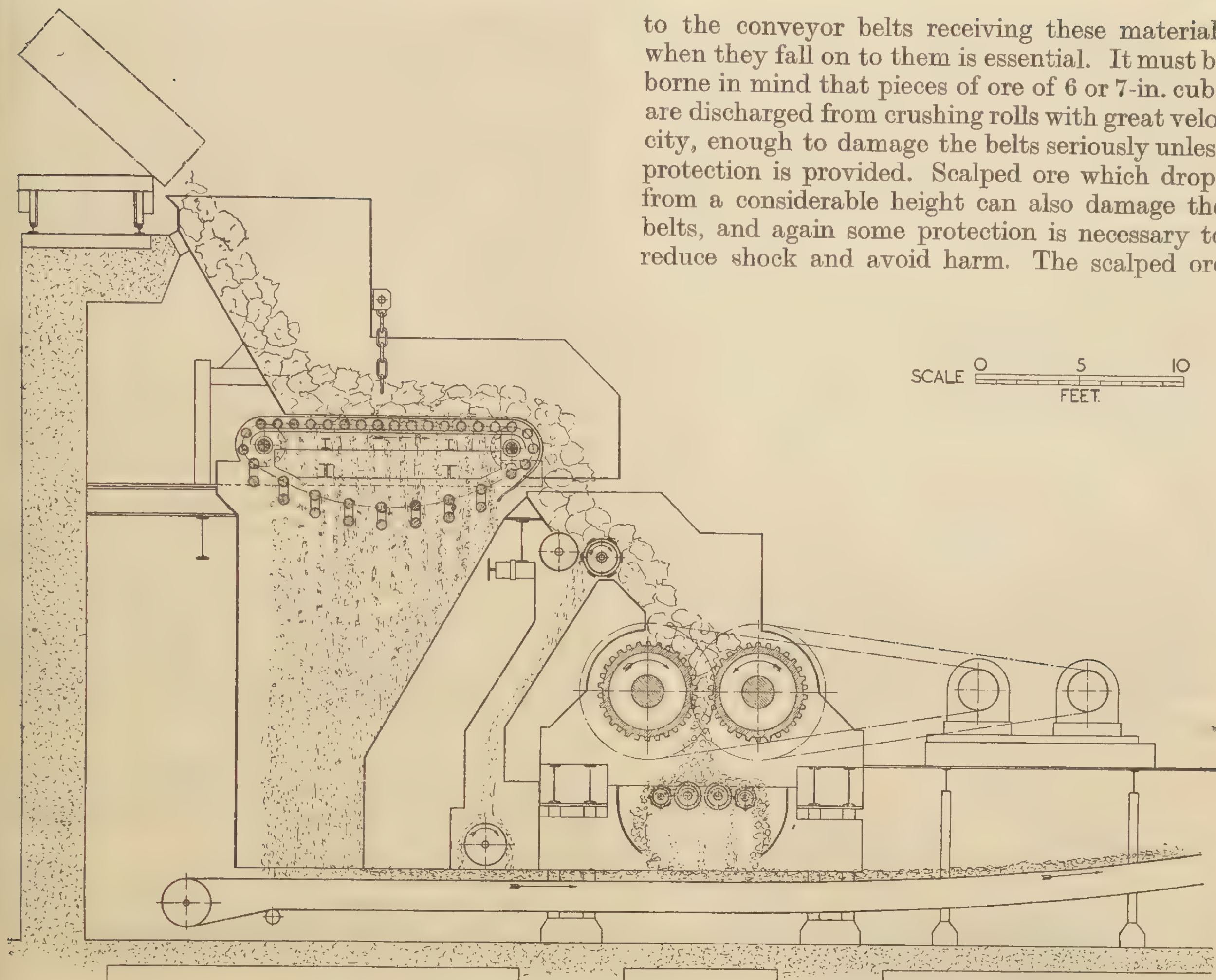


FIG. 2—Primary crushing plant, Oxfordshire Ironstone Co., Ltd.

may be deposited on the belt passing below the primary crusher and so form a protective layer of ore to receive the material being ejected from it. In addition a set of grizzly rolls may be interposed between the crusher and the belt. The arrangement shown in Figs. 2 and 3 illustrates this feature, while Fig. 1 shows a somewhat similar arrangement which was not sufficiently adequate in operation to protect the belt from serious and expensive damage.

the author is connected over 600 tons/hr. have been fed into the receiving hopper continuously for many hours each day with such an arrangement as is shown in Fig. 1. The arrangement shown in Fig. 3 is designed for a continuous intake of 800 tons of ore per hour if desired. As the size of ores from adjacent quarries or even from sections of one quarry varies widely, the scalping screens and the crusher must each be able to deal with almost the full tonnage entering the plant at any given time. The ores from some quarries may consist largely of smalls, *i.e.*, material below 3 or 4-in. cubes, and from others only a small proportion, approximately 10–15%, is of this dimension. Extreme cases have been quoted, but they occur, and necessitate the design of equipment of ample capacity to deal with peak loads comfortably.

The scalped ore and primary-crushed ore may be disposed of separately or combined to pass to secondary crushing. In either event protection

If primary crushing alone is adopted all crushed and scalped material may be sent onwards by belt for loading into wagons or further conveyance to furnaces. Better still, it may be screened into two or three grades, such as 0–$\frac{3}{4}$-in., $\frac{3}{4}$–$1\frac{1}{2}$-in., $1\frac{1}{2}$–7- (or 8-) in., which can be disposed of as desired, but preferably with the fines being sent to the sinter machines and the other fractions charged direct into the furnaces as separate rounds.

When secondary crushing takes place, all the ore under $2\frac{1}{2}$-in. cube should be screened out

before entering the crusher, thus eliminating the product which is already of the final dimension or below it. This relieves the load on the machine and again obviates making further fines which, of course, must also be prepared in suitable form for the furnace. Screening will follow to separate the grades of ore as required for the succeeding processes.

Feeding the Crushing Plant

It is perhaps unnecessary to indicate that ores for crushing, whether foreign or home ores, must in most cases be transported to the plant by railway. This fact alone has a bearing on the method of feeding the ores into the crusher receiving hopper. It would appear that a tippler is essential in order to permit of ore wagons being speedily emptied. The large pieces of ore which are commonly loaded by mechanical shovels create difficulty with bottom-discharge hopper wagons. Further, the presence of large amounts of fines in a moist and sticky condition causes the wagon load to hang up in hopper wagons, and much valuable time and labour can be expended in poking and clearing them. Of course, hopper wagons can be built with suitable discharge arrangements to avoid this trouble, but they are naturally expensive and necessarily large. Justification for such hoppers depends on the magnitude of the crushing operation and tonnages being handled, but for normal plants, such as have been built up to the present in this country, a good robust tippler deals with this problem more cheaply by enabling a simpler ore wagon construction to be adopted.

Crushers

There is naturally some choice as to the type of machine to be adopted and it can be said that all types can be usefully employed for one or other of the stages in crushing, provided that care is taken not to create the conditions which are deleterious to any particular type.

It is true to say that there is greater potential danger of plugging, say, a jaw crusher or a Pennsylvania crusher with wet ores than there is with a two-roll machine unless the original fines are scalped out. The author's preference is for the two-roll machine as a primary, particularly because of the ease with which it disposes of the very large lumps of ore which come its way. Pieces of ore 6 ft. × 4 ft. × 2 ft. are disrupted in a matter of seconds, and the crushing rate may rise to a value of three or four times the normal on such occasions.

Such machines are expensive, but no more so than the jaw crusher capable of dealing with the same masses of ore. Naturally, they must also

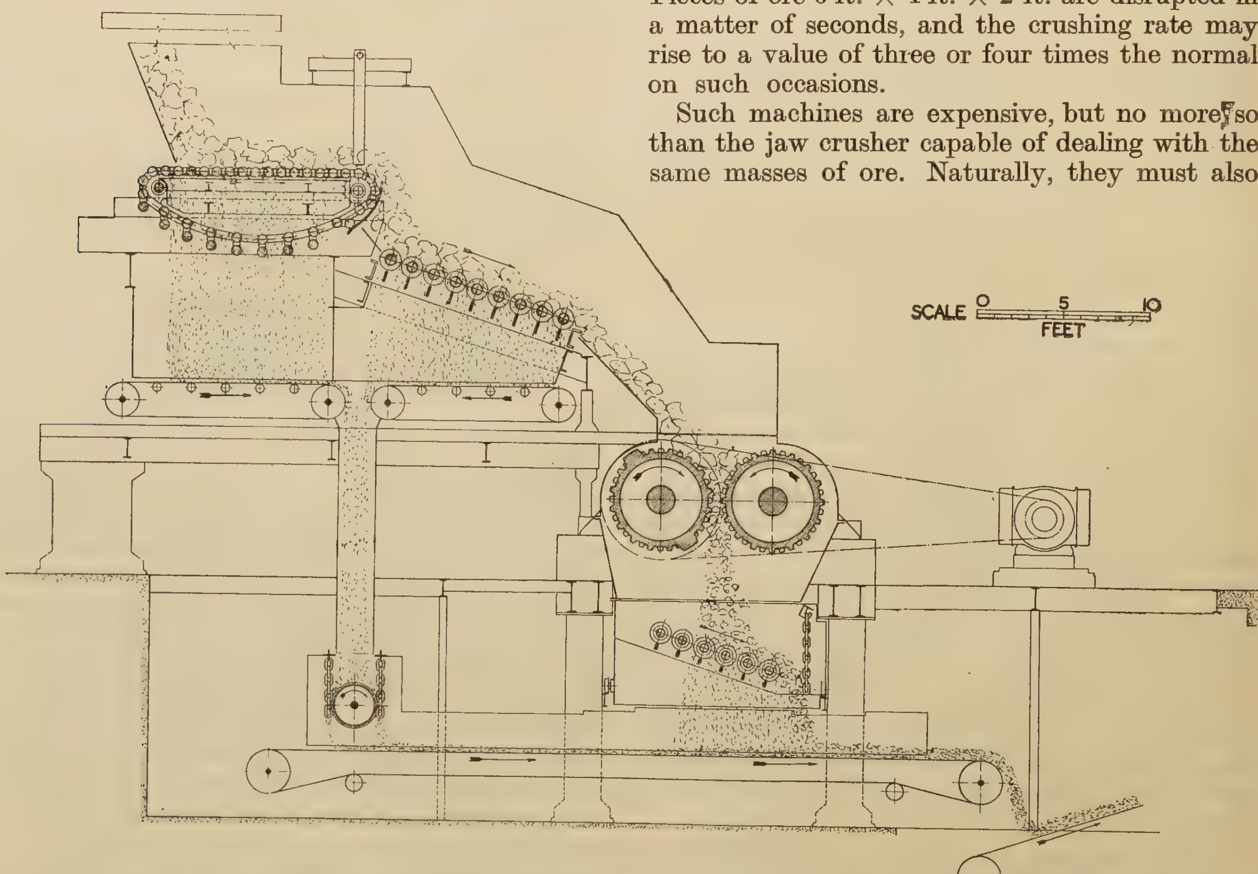


FIG. 3—Primary crushing plant: New ore-preparation plant, Messrs. Stewarts and Lloyds, Ltd., Corby

be looked after properly, and by keeping them adjusted to accommodate wear of the roll knobs and, further, by welding the knobs systematically, replacements can be kept to a minimum.

For secondary crushing, two-roll, jaw or gyratory types can be adopted. The layout illustrated in Fig. 4 shows a primary two-roll machine followed by two 7 ft. 6-in. dia. gyratory secondary machines crushing to $2\frac{1}{2}$–3-in. cube final product. The gyratory type was selected in this case because of the possibility of having reduced quantities of oversize slabby material delivered from them, and also in view of the necessity of maintaining the utmost regularity of dimension of the crushed ore.

With ore less prone to breaking into slab form there is no doubt that a two-roll crusher is suitable for secondary crushing, as is also no doubt the case with jaw crushers. In the case of the last-mentioned type there is a marked tendency to produce more fines than with the other types. An existing ore-crushing plant at the works with which the author is connected employs two-roll secondary machines, but in a new plant under construction the gyratory type is being installed in the expectation that an improved performance will be obtained.

Figs. 3, 5, and 6 show typical crushers of the three main types mentioned, and it is certain that all are very good, with each having some slight advantage over the others for particular duties.

Before passing from the crushing plant proper it is desirable to call attention to two troublesome features resulting from the processes. One is the dust nuisance arising from the crushing of ores, and attention is needed in preparing new designs for the provision of simple dust-extraction plant at the primary crusher. The second is the attention which must be paid to chute design in order to avoid accretions of wet, sticky fines dropping from one level to another. Straight, almost vertical, sides are essential, together with easy access for poking-down the accumulations which usually occur in wet weather and with home ores.

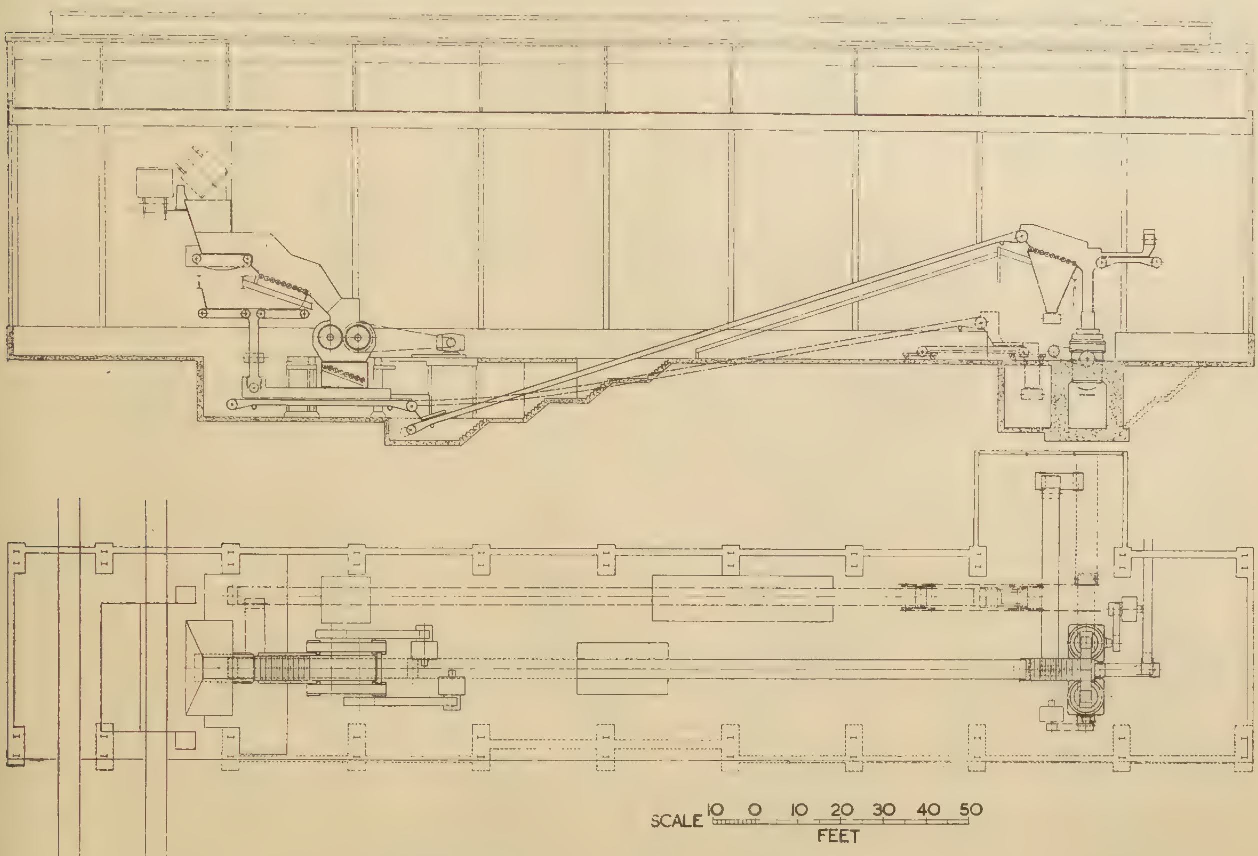


FIG. 4—Layout of crusher building: New ore-preparation plant, Messrs. Stewarts and Lloyds, Ltd., Corby

Screening

It has been largely accepted in the past that vibratory screens are entirely suitable for screening ores. This may be true with dry material,

but it is certainly not the case with ores which are wet and sticky. Much delay and hindrance to crushing-plant operations can be caused by clogging of the screens, with the result that undesirable fines pass over with the large material. Separation being incomplete, the operator's natural recourse is to replace the plugged screen cloth by others having a more open mesh. The opposite effect begins to be felt in this case, and a large amount of oversize smalls passes through the screen with the fines. When the fines are to be used for the sintering process this is very undesirable.

Various means to aid the screening process by ensuring that screen cloths are kept open can be adopted, such as the regular addition of flue dust to the materials before screening, or the extraction of a proportion of the material to be screened at a suitable point in the system and partially drying it, thereafter restoring it to the main stream of ore, again before screening. Both these methods are effective for the purpose intended, but they introduce complication by requiring costly plant and sub-processes, which in turn require additional labour and maintenance.

At the works with which the author is connected some work has been carried out in this direction, based on the conviction that it is possible to effect the screening of ores in sticky condition without

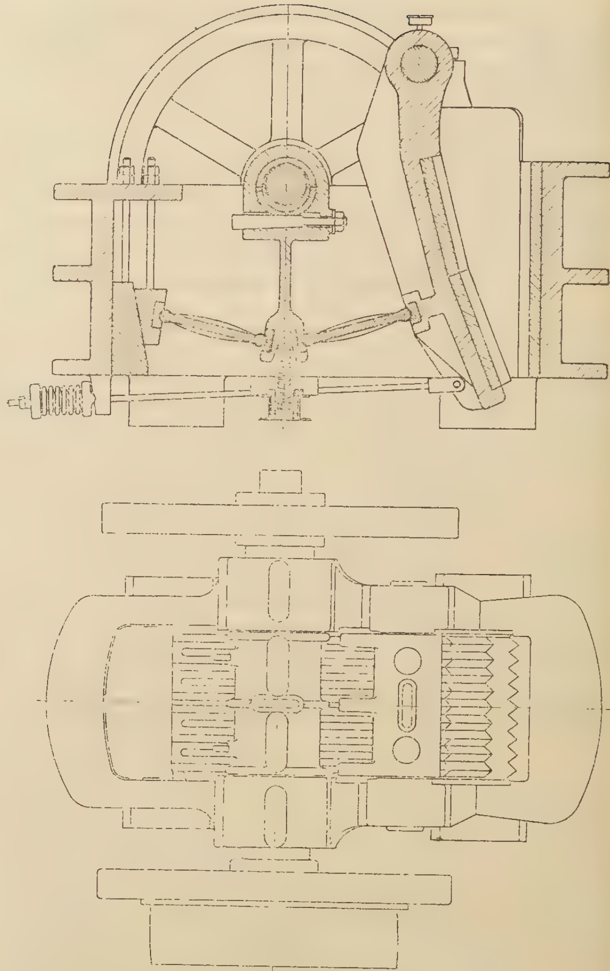


Fig. 6—Jaw crusher

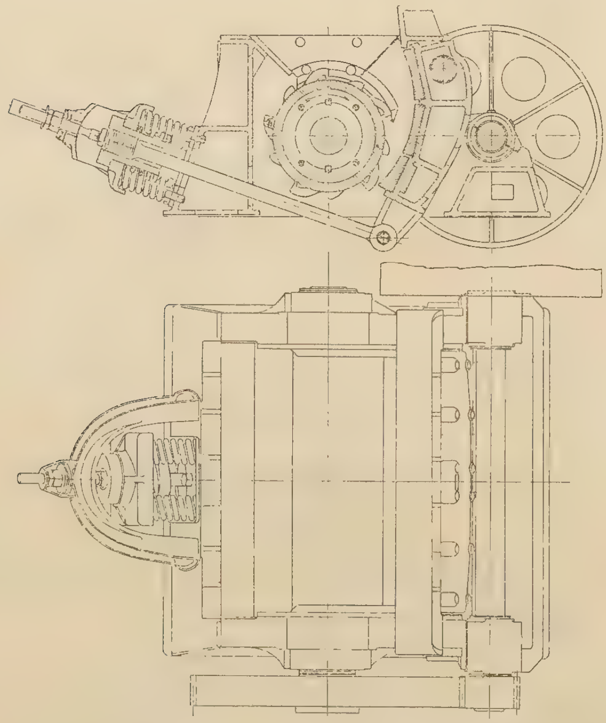


Fig. 5—Single-roll crusher, Pennsylvania type

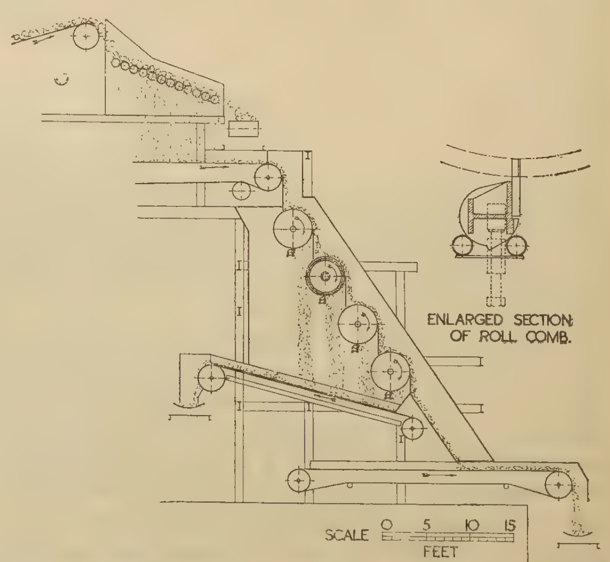


Fig. 7—Final screen: New ore-preparation plant, Messrs. Stewarts and Lloyds, Ltd., Corby

recourse to drying or adding flue dust. Results obtained have been encouraging even to the extent of separating material of $-\frac{3}{8}$-in. size, from wet ores, and a screening plant at present under construction is designed for operation on a production scale and utilizes the principle evolved by experiment. This involves the use of a series of grooved rolls in cascade arrangement, with the ore dropping about $3\frac{1}{2}$ ft. from roll to roll. Fine ore penetrates the grooves and coarse material passes over. Balled fines are broken up by impact on the collars forming the grooves, and by dropping the ore from roll to roll a very good degree of separation of fines is obtained. The arrangement is shown in Fig. 7, and experiment has shown that it is effective with ores of all degrees of wetness and stickiness. The idea of using grooved rolls for separating of materials is not a new one, but it is believed that the arrangement of rolls and the application are novel.

Blending

To ensure regularity of product from the blast-furnace it is essential to charge raw materials of uniform composition.

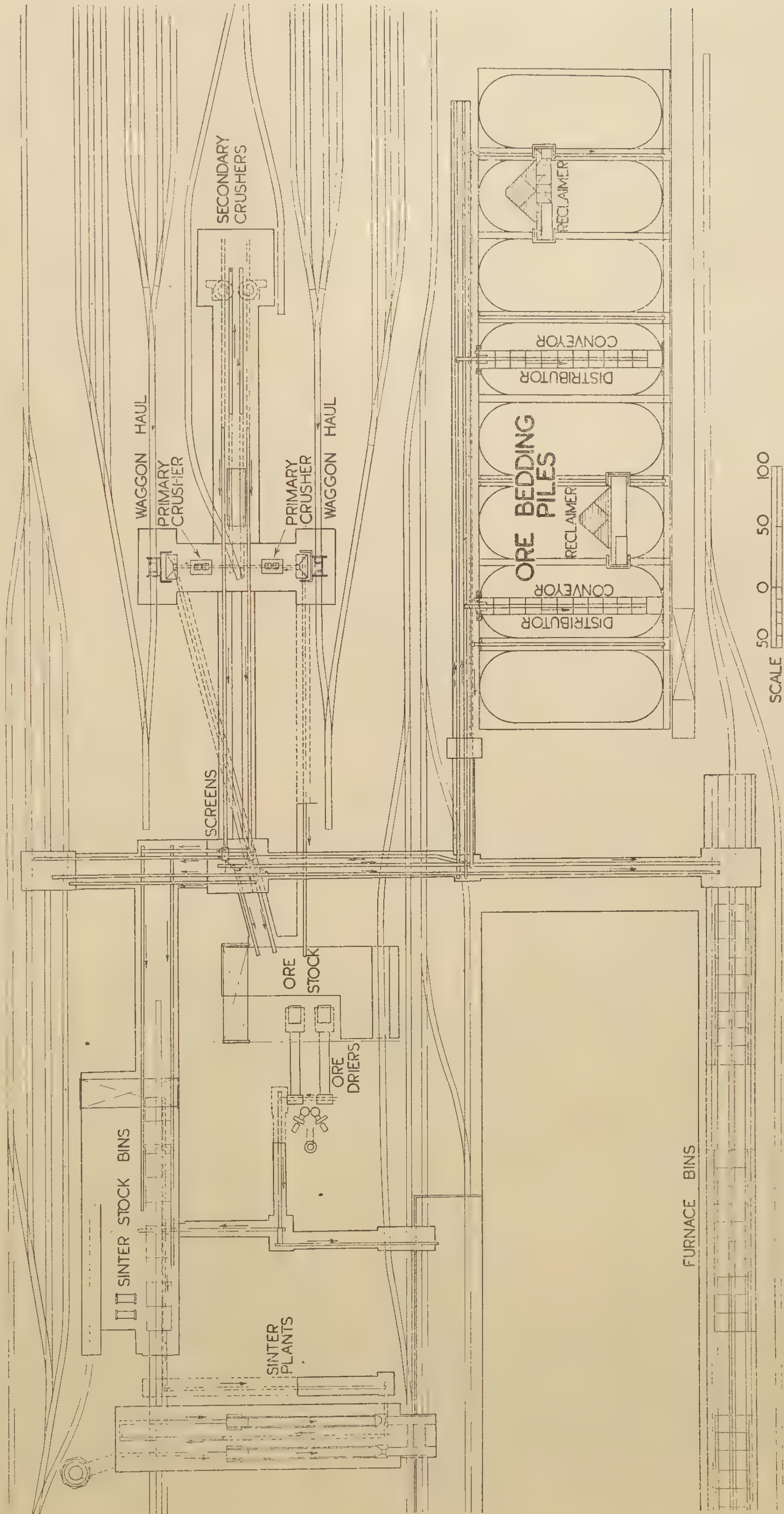


Fig. 8—Ore-preparation plant, Appleby-Frodingham Steel Co., Ltd.

That is, the diversity of ores being utilized should be thoroughly blended or mixed preparatory to charging. To ensure this, some form of blending plant is necessary. Two installations for mixing ores are shown in Figs. 8 and 9. Both are of the same type, although the layouts differ. The principle employed has been ably outlined by Elliot.* Briefly, it is to distribute the different qualities of ore in layers along a bed, thus building piles of ore from layers of different chemical composition. The ore is reclaimed by a machine slowly travelling along the length of the piles and raking down the various ores from the full cross-section of the piles on to a cross conveyor which deposits the ore on a suitable conveyor system for transfer to the blast-furnaces.

Rudimentary methods of mixing ores are still employed, but the results obtained by the use of the improved plant shown in Fig. 8 have without doubt justified its installation and point the way for further developments. Experience of the fluctuations in iron quality resulting from poor

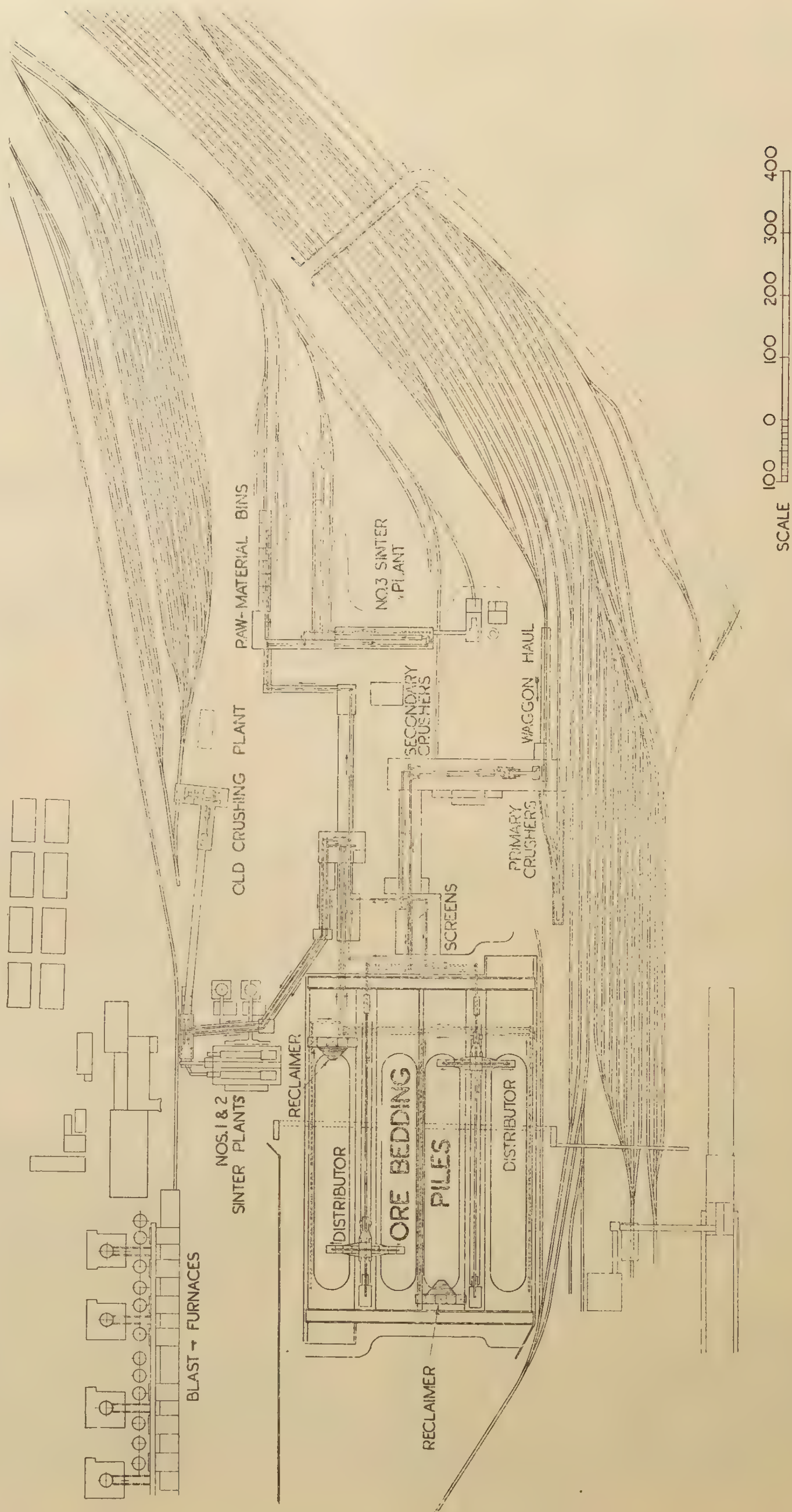


Fig. 9—Ore-preparation plant, Messrs. Stewarts and Lloyds, Ltd., Corby

* *The Iron and Steel Institute*, 1944, *Special Report No.* 30.

methods of mixing ores has convinced the author of the necessity for improvement in this respect. Fig. 9 shows the mixing- or bedding-plant layout at present being installed at the works with which the author is connected, and attention is drawn to the extent to which the type of plant shown in Figs. 8 and 9 has been utilized in the U.S.A. and in Germany.

Attention is drawn to the main difference between the layouts of the mixing plants shown in Figs. 8 and 9. That shown on Fig. 8 utilizes an overhead conveying system to distribute ores to a number of comparatively small piles, while the layout on Fig. 9 is designed to form piles of any required length and capacity up to the maximum. In this case two travelling wing tripping machines deposit ore to right or left as required and the two main feeding conveyors run on floor level, rising up the trailing conveyor frame attached to the travelling tripper. This general arrangement permits of easy extension of the piles in the event of increased requirements of crushed and mixed ores in the future, and the beds can be lengthened without interrupting normal operations. It is intended to bed the fine ore screened out after crushing and so obtain a uniform reclaimed mixture for sintering. As circumstances may arise in operation which demand greatly accelerated rates of recovery from the bedding piles, facilities have been provided for employing both reclaiming machines on a single bed simultaneously to deliver ores on to a common belt.

It will be observed that the arrangements shown in Figs. 8 and 9 make extensive use of belt-conveyor systems for collecting and distributing ores to central points for further despatch by rail to furnace bins or for export to other works.

Sintering

The sintering process can to some extent be regarded as one of beneficiation, although it is naturally one which is essential to convert ore fines, undesirable in themselves for furnace use, into a form which will at least enable them to be used freely and confer some benefits to furnace operation and output.

There is no doubt that much bad sinter is being made today, not so much because operators do not know how to make good sinter but largely because the fundamental problems of preparing and assembling the necessary raw materials have not been completely solved in many cases. The

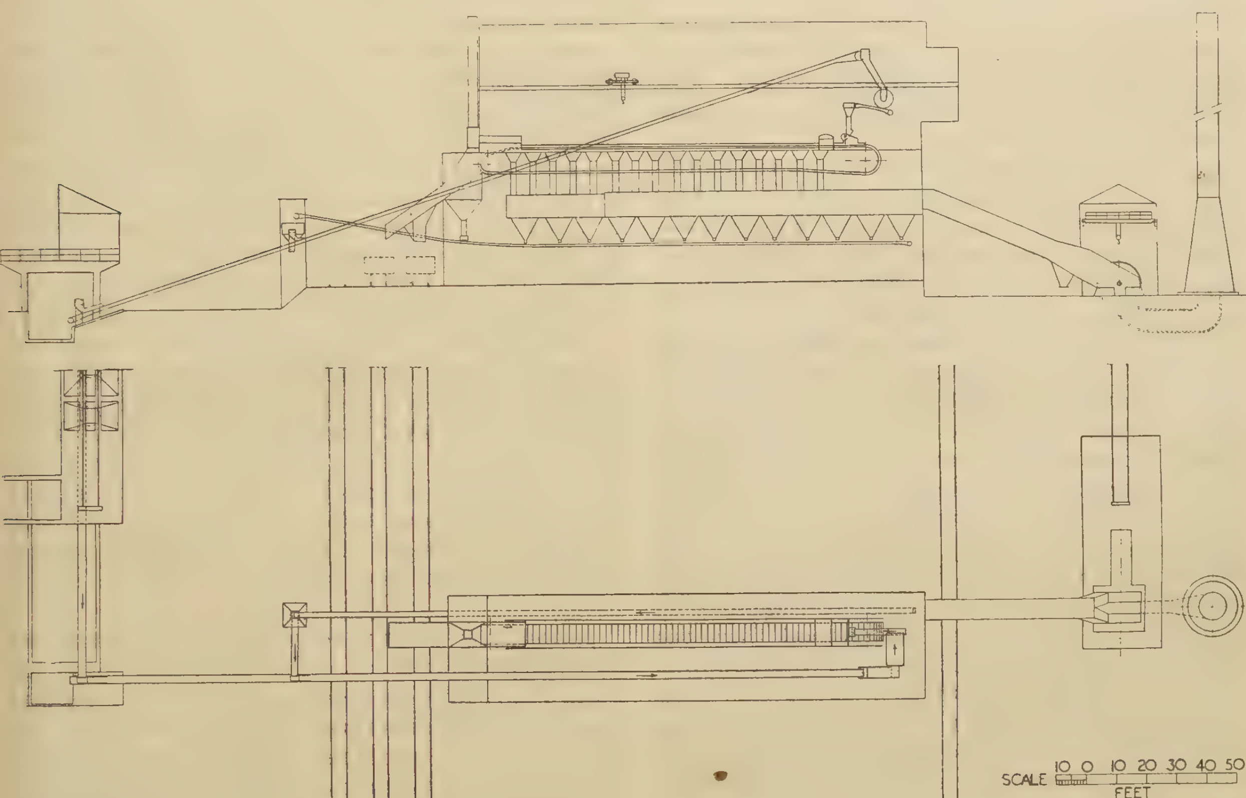


FIG. 10—No. 3 sinter plant, Messrs. Stewarts and Lloyds, Ltd., Corby

sintering process is, therefore, often a case of making the best of a bad job with the plant as built.

A typical sinter plant of recent construction is shown in Fig. 10. The raw materials are assembled in the bins, being transported there by rail. No preparation of the ore fines takes place other than screening, which suffers, as pointed out earlier, from deficiencies in the type of screens used. Adjacent ore bins more than likely contain ore fines of distinctly different types, and all ore bins do not usually contribute to the feed to the plant simultaneously. This is wrong in principle, and in the bedding plant shown on Fig. 9 it is intended to pre-mix all ore fines and thus supply a uniform mixture to all the raw-material bins feeding the sinter plant.

Again, coke breeze is supplied as obtained from the coke-oven screens or as bought. The variations in size of breeze are remarkable and cause great difficulty in operation, being responsible in a large measure for poor-quality sinter. This should be rectified by additional crushing plant for the sizing of breeze.

In Fig. 9 it will be noticed that all the sinter-plant raw materials will be assembled at the bins by belt conveyor, and although railway connections will be retained they will serve in emergency only. Batch transport by rail is costly and requires considerable labour for handling.

It is true to say that neither plant manufacturers, designers, nor operators have given sufficient attention or thought to the problems of building the best plants for making the best product. Nowadays it must be conceded that a saving in original capital expenditure can be the source of a constant loss which, in the long run, will outweigh the original saving. Full benefits from the process cannot be obtained under such limitations. Sinter plants suffer considerably in operation, as can be well understood from the combined effects of rapid wear and corrosion and erosion and, in the author's view, too little attention has been given in the past to finding proper solutions to these problems. It has been too easy to combine various units comprising a plant in the hope that, because they are good in theory and in some practical applications, they will give maximum efficiency and performance at all times. In the author's experience with continuous-operating sinter strands some typical problems which have arisen in practice have originated in the design of pallets and the materials of their construction, the use of draught-regulating valves in completely hopeless positions, in the choice of fans for creating the necessary draught, corrosion and erosion of unprotected plating in ducting and even in lined steel chimneys, in sinter-machine discharge and driving ends and, finally, in the fact that sintering is a hot process.

Having mentioned some of the problems associated with sinter-plant machinery, a few brief remarks on them are necessary. Dealing first with pallets, orthodox construction has made large use of cast iron. In the author's view, cast-steel, or better still, mild-steel construction is preferable. While the last-named material may not stand up quite so well to the warping and distortion which occur under repeated cycles of heating and cooling, it is possible to do something to rectify distortion and repair damage ; this is not so readily possible with cast iron. Cast steel possesses similar qualities, although it may be dearer in first cost.

Having had considerable experience with exhaust fans running at different speeds on sinter plants, the conclusion reached by the author is that the lowest speed of rotation possible, consistent with obtaining the necessary draught, should be used. Fans running at 1400–1500 r.p.m. provide more than enough maintenance trouble in comparatively short periods, owing to the state of unbalance which quickly sets in from erosion by the inevitable dust present in the exhaust gases. This is still present in the gases even although dust-eliminating cyclones are provided.

Great care in designing exhaust stacks is necessary if troubles are to be avoided. It is not sufficient to build a steel stack and simply install a brick lining. Protection against corrosion from within the shell is essential, and a good case can be made for an all-brick chimney for this application. These are only a few examples of the incomplete thought which is given to plant design, and they by no means cover the entire field.

As outputs of furnace plants are increased so their requirements of sinter are raised, and as more preparation is given to ore more fines arise, making an increased use of sinter inevitable. It becomes more and more essential, therefore, that the sinter plants should operate continuously and be free from the costly delays which arise from inherent defects.

Very few sinter plants are equipped with adequate screening for the sinter and improvements in design for this purpose are necessary. In the future, designs should allow for taking the hot sinter as discharged from one or more plants to some adjacent point for cooling and then proper screening. It appears to be a useless waste of fan power to suck air through the hot sinter on the bed for the purpose of cooling after the sintering

process is completed. An unnecessary load is added to the suction fan. The result is always the same, however, in so far as operators extend the production of the plant to the maximum and discharge the sinter hot over a fixed grillage of rails for rather poor screening and so into wagons or skips.

Ore Preparation at Salzgitter

A paper such as this would hardly be complete without some reference to one of the most recently built plants for dealing with ores on the grand scale, namely, that at Salzgitter, in Germany, which the author had recently the opportunity of inspecting.* The ore-preparation plant, situated near the ironmaking plant, embraces all of the processes previously dealt with in this paper and in addition provides for ore beneficiation by utilizing the Lurgi ore-roasting process with magnetic concentration.

The Salzgitter plant is self-contained and receives all raw materials by rail in special hopper wagons eminently suitable for their purpose. Interplant materials-handling is entirely by conveyor system, but prepared materials destined for the blast-furnaces are again transferred by rail to the furnace bins. The distance between ore preparation and the furnaces is about a mile, and batch transport by rail is the most suitable method of feeding the blast-furnace plants.

Some of the Salzgitter ores reaching the preparation plant have already been concentrated by crushing and washing, and these are passed to the stock bins for the sinter plant. The large uncrushed ores are deposited in concrete bins which feed a battery of six primary two-roll crushers which break down the ore to – 6 in. They in turn feed a battery of 12 smaller two-roll crushers which break down the ore to – 2 in.

The qualities of ores in fit condition for bedding then pass to the bedding plant after removal of fines. The bedding plant is of the overhead-conveyor type similar to that shown in Fig. 8, with the elaboration that the bedding piles are completely roofed over. Whether or not this is necessary is a matter of opinion, but in any case so much of the ore was derived from underground that it was comparatively dry and it was preferred to keep it in this condition. Other ores are further crushed in 12 tertiary crushers of the smaller two-roll type to $-\frac{3}{4}$-in. for conveyance to, and concentration in, the Lurgi plant. Materials passing directly for sintering are conveyed to the assembly bins, which also receive the coke breeze crushed in two-roll machines to $-\frac{1}{8}$ in., returned sinter fines, flue dust, &c.

The general layout of the ore-preparation plant is shown in Fig. 11, and a short description of the sintering and concentration plants will be of interest.

Sinter Plant

Eight sinter machines were projected but only six are completed and operating. The remaining two are nearly ready for operation.

The raw-material bins feed six drum-type open-end mixers which in turn feed the sinter machines by distributing conveyors running up to the hearth layers. Interesting features of the preparation of the materials for sintering are the very extensive coke-crushing plant (shown in Fig. 12) and a limestone-grinding plant. Ore of suitable small size is screened out at the screening plant and conveyed separately to the sinter machines to provide a bedding layer for the hearth.

The sinter machines are of similar design to, but larger than, several built in this country. Each machine hearth is $8\frac{1}{4}$ ft. wide and 148 ft. long. The pallets are built in two pieces machined and bolted together. Rollers at the sides support the pallets on rails which were somewhat unusual in construction, being formed of thick rubber, capped with steel strips about $\frac{3}{8}$ in. thick, the object being to provide a slightly yielding support for the pallets, to permit of them rubbing very lightly on the fixed wind boxes of the machines. While the operators claimed that this was effective, it was noticed that the rail strips were becoming bent and broken, wheels were wearing slightly, and the rubbing between the pallets and wind boxes was increasing. The intention was to provide a reasonably good seal to prevent ingress of air into the suction system, but, while this no doubt functioned correctly at the start-up of the new machines, it was evident that the process of deterioration had commenced.

The wind boxes were each fitted with a gate valve for draught regulation, but here again the inevitable corrosion and wear were taking place and they were being discarded without any substitute being used for them.

Very good quality sinter is being made in these plants and it is discharged fairly cold from the pallets on to rotating-paddle breakers and thence on to long jigging conveyor screens which remove the $-\frac{1}{2}$-in. material. Sinter fines and dust from exhaust tubing and cyclones are conveyed to the raw-material bunkers and are ultimately returned to the sinter machines. The screened sinter is loaded into suitable hopper wagons for transport to the furnaces or to other areas.

* British Intelligence Objectives Sub-Committee Report, No. XXXII—119, BIOS 592.

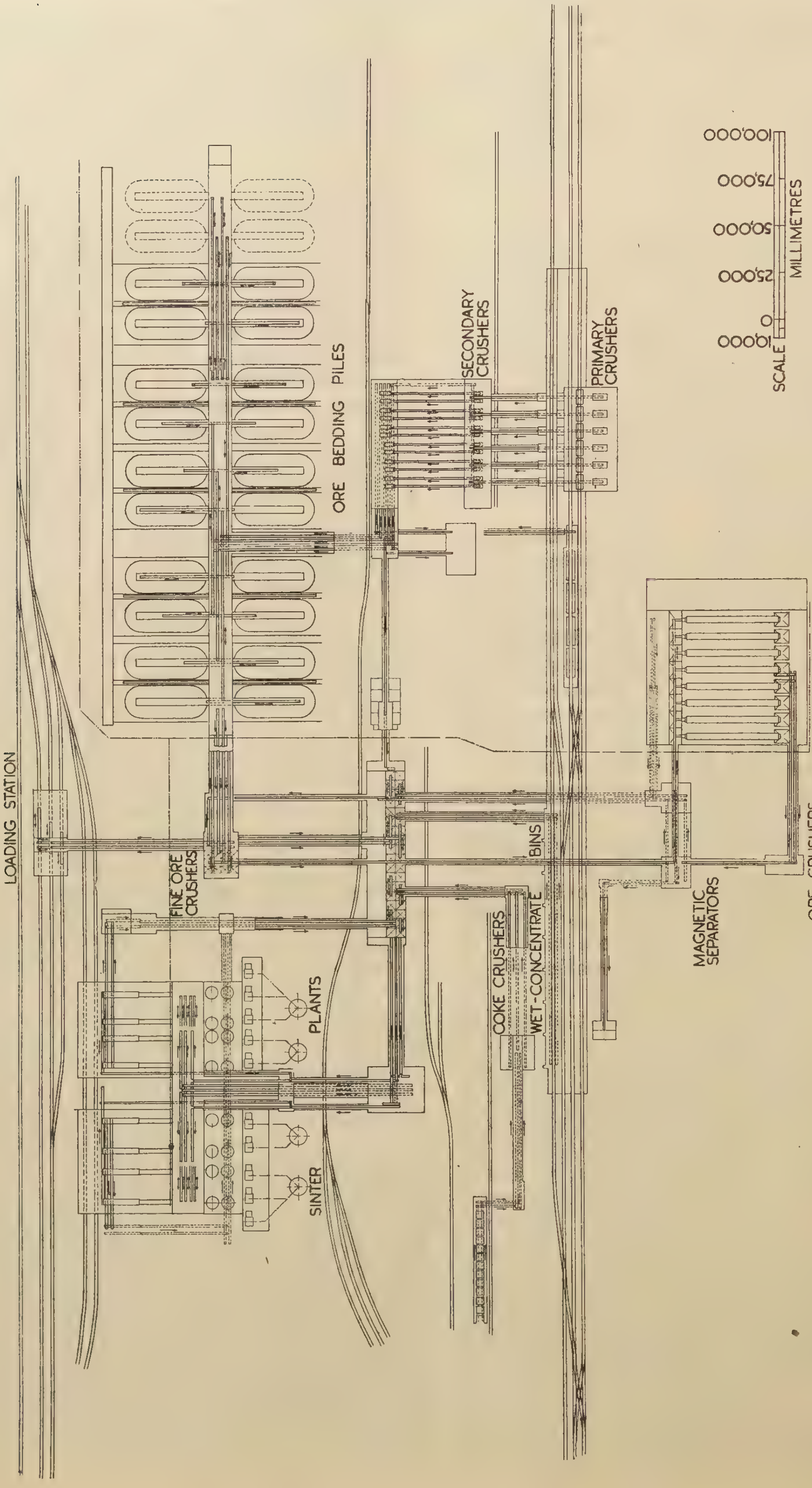


FIG. 11—Ore-preparation plant, Hütte Braunschweig

The exhaust gases from each sinter machine are passed through two cyclones for dust separation before reaching the fans. The cyclones are lined with abrasion-resisting tiles and it was claimed that no trouble owing to accretions of damp sinter dust choking the small outlets had been experienced. This may be doubted, because there was evidence of damage to ducting and fans by dust erosion and corrosion.

The fans are of double-inlet impeller type, running at 1480 r.p.m. and exhausting 210,000 cu. ft. of gases per minute. The impellers are about 3 ft. 6 in. in dia., but do not last long under the conditions of service. In general, the fan construction is solid and seems to be able to withstand the slight unbalance which certainly crept in with operation. The entry ducting to the fans was corroded and abraded, and was being patched extensively. The fan impellers give a life of 6–12 weeks, although expectations were for a greater life than this, *viz.*, up to 8 months.

Motors are direct coupled and start direct on the line, and mortality is high for various reasons. They operate at 6000 V. and loads are controlled by a damper on the inlet to the fan. Gases are discharged into brick chimneys, each large enough to serve two sinter machines. The chimneys are remarkable for their size (21 m. in dia. at the base and 150 m. high); this height was necessary to comply with the laws relating to the discharge of objectionable gases into the atmosphere. The chimneys are brick built and coated inside with an acid-resisting lacquer and outside for about 60 ft. at the top.

The sinter machines are each rated at 800 tons output of saleable sinter per 24 hr. It should be noted that the sinter is discharged from the machines cold, having been cooled by air drawn through the bed after sintering was completed. This imposes extra load on the suction fans and requires additional length of machine for the purpose.

Ore Concentration

Three ore-concentration methods are in use at Salzgitter, namely:

(1) Wet washing following fine crushing of argillaceous ores.

(2) The Krupp-Renn process, which produces almost a metallic product.

(3) The process of magnetic concentration following fine crushing and roasting in Lurgi kilns.

The first method is in use at the Calbecht ore mines, and the concentrate is delivered wet

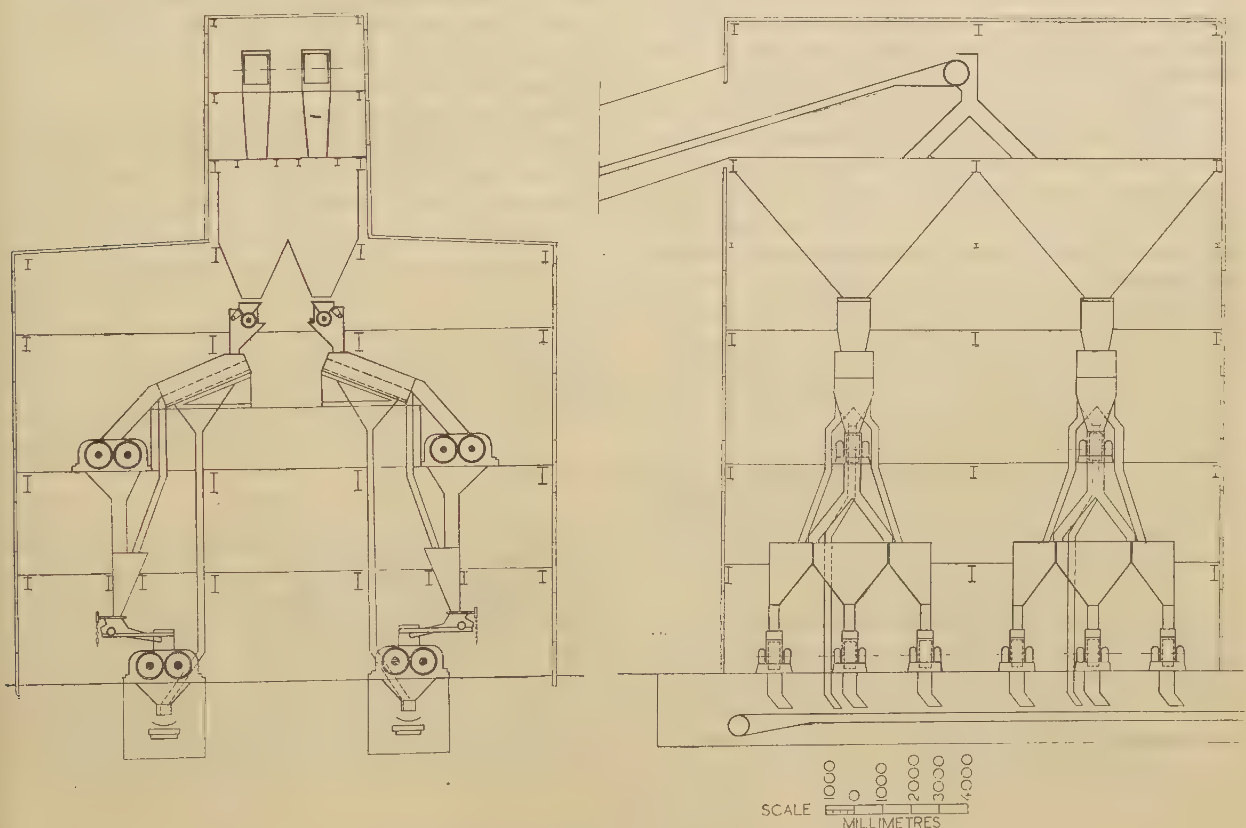


Fig. 12—Coke-crushing plant, Hütte Braunschweig

in hoppers to the sinter plant at Salzgitter. It is not proposed to discuss this method in detail as it does not really form a part of the integrated ore-preparation plant, although it is worthy of minute description elsewhere.

The second method also was not regarded as being part of the ore-preparation plant and although the management at Braunschweig had some interest in its operation and at one time supplied the necessary raw ores, they did not make use of the product from the Krupp-Renn process at the blast-furnaces. Indeed, they regard it as too costly for their furnace burdens and are content to see it transported by barge to the Ruhr.

The third process forms an integral part of the ore-preparation plant and plays a large part in preparing materials for sintering. The requisite plant is extensively laid out and again it is evident that no expense has been spared in building a plant suitable for its purpose. Some notes on the plant follow.

The Lurgi Plant

A Lurgi kiln is shown in Fig. 13. Two-roll crushers broke down the secondary-crushed siliceous ores from – 2 in. to – $\frac{3}{4}$ in., and in this condition they were conveyed to the Lurgi kilns' receiving hoppers. A battery of eight rotating kilns was built, although they had not all been in use at the time the plant was shut down.

The kilns are all about 12 ft. dia. × 160 ft. long and are lined with abrasion-resisting firebrick. Fine ore is fed at the high end into the kilns, which lie at a slope of about 5°, and blast-furnace gas is supplied at the opposite end. The kiln weighs 300 tons and the lining about 300 tons, and each kiln carries about 300 tons of fine ore in process. The total weight carried on the two trunnion rings therefore amounts to about 900 tons. The whole rotates at about 3 m./min. peripheral speed, and is driven by a 64-kW. motor.

As the process is designed to change the oxides of iron into magnetic form, Fe_3O_4, heat is supplied for this purpose only, the maximum temperature being 750° C. in the middle of the kiln. Eleven burners are fitted in spiral formation along the kilns. Blast-furnace gas is led along the outside by six rectangular ducts which receive the gas from the low-end main gas supply. A connection from one or other is taken to each burner. In a similar manner, air is blown by fan along six similar ducts from the high end of the kilns. Gas supplies are controlled by gate valves at each burner, as is also the air. Only enough gas is burned to keep the temperature gradients inside the kiln at the proper values, and control is obtained by the liberal use of thermocouples distributed over the kiln length.

The fine ore gravitates along and down the kiln, and is fed or dropped through the stream of blast-furnace gas by means of curved high-chromium/vanadium cast-steel plates projecting from the brick lining inside the kiln and spaced at intervals of about 30°. They lift the ore and drop it continuously as they pass round the upper three-quarters of the complete circle. Naturally, a body of ore lies on the bottom of the kiln and to one side.

The incoming ores extract heat from the waste gases, which leave the kiln at 150° C., and the processed ore gives up heat to the main stream of incoming blast-furnace gas; and to ensure that the roasted ore is at suitably low temperature at

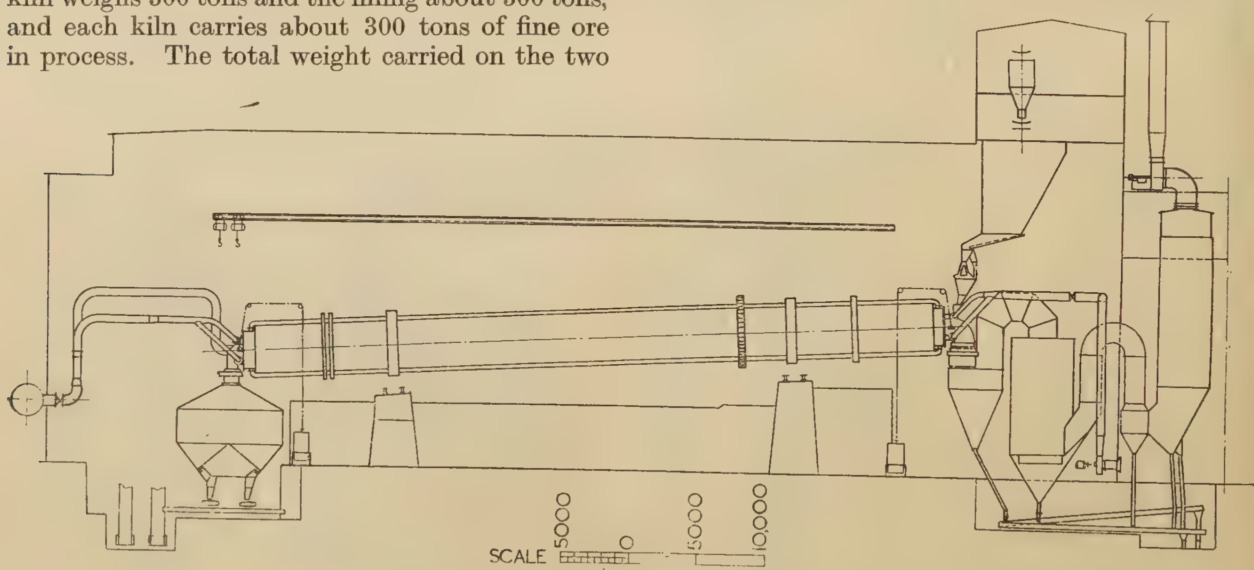


FIG. 13—Lurgi kiln, Hütte Braunschweig

discharge, water is sprayed in along with blast-furnace gas. The process is completed over a length of about 8 m. near the middle of the kiln.

The waste gases pass first through two ordinary dustcatchers which remove dust totalling approximately 4% of the ore charged. This dust is returned to the kiln by a Fowler pump. An electrostatic unit follows the dustcatcher and removes a similar quantity of dust, which is fine enough to find a market as pigment.

The ore discharged from the kiln is reduced to $-\frac{1}{8}$ in. in two stages of crushing and is passed over magnetic separators. The separator rolls are thin shells of brass or non-magnetic steel, with the magnetic field applied internally. Three D.C. machines serve each kiln, but A.C. was being installed to give greater efficiency of separation. An average recovery of 82% of the iron in the original ore was realized during 1943 and 1944, in the form of a concentrate containing 40% of Fe, compared with 27% of Fe in the ore and 13% of Fe in the tailings. A 90% recovery was expected from the A.C. separators.

This process, with the massive equipment utilized, is naturally accompanied by several major problems.

The 900-ton kiln is supported by two trunnion rings on rollers, and its natural tendency to run downhill is corrected by setting the rollers slightly askew, imparting an equal force up-hill. Much attention was given to the design of the ends of the kiln, first to reduce the risk of explosion to a minimum, and secondly to take up the eccentricity of movement to be expected from such a massive heated steel shell. Fig. 13 gives some idea of the suspended end-pieces which, on one face, bear against the revolving ends of the kiln and bend round into a water seal. This gives complete freedom of movement to accommodate any eccentric motion, and any sudden rise of pressure in the kiln is immediately released through the seal. A quick-filling device guards against subsequent entry of air.

Conclusions

From the preceding general descriptions of plant used in the various processes of ore preparation it will be clear that all are dependent on a very high degree of mechanization. The quantities of materials treated are very great, and the closest degree of integration between one step and the others must be maintained at all times. This of necessity leads to the very extensive use of conveying systems, as is clearly shown in Figs. 8, 9, and 11.

The railway plays its part in bringing batches of materials from distant sources to the ore-preparation plant and also in transferring prepared products to the furnace plants, but it cannot play any effective part in the interstage handling of materials in any modern ore-preparation unit.

The use of conveying systems is gradually being extended, and a logical development would be the transfer of prepared ores directly by conveyor to the blast-furnace bins. This is readily possible if the ore-preparation plant is in close proximity to the furnace plant, but naturally it will cease to be economic when they are widely separated. In all modern blast-furnace plants coke is conveyed directly to the furnace bins satisfactorily, and there is no reason which mitigates against the direct conveyance of ores.

There is some evidence to show that plant manufacturers have a great deal to learn about the applications for which they put forward their designs. Many problems, and indeed faults, continue from installation to installation. So often the builder's interest is confined to the construction of a unit of plant, its installation, and start-up. Again, the design may be more or less standard and adapted from some other use to which it was originally applied.

The engineer responsible for purchasing the plant and approving manufacturers' designs are to an equal degree at fault. The author would, therefore, make a plea for much closer collaboration between operators and builders of plant at all times, so that the progress in design can be continuous, and builders may obtain the latest information on problems arising in operation, and operators the opportunity to disseminate the useful information which they collect from day-to-day contact with their plant.

The means for "getting together" locally has always existed and can still be used. In addition, today we have a very useful body, the British Iron and Steel Research Association, which in time can render most valuable service to operating firms and manufacturers by focusing its attention on all problems of primary importance.

Acknowledgment

In conclusion the author would like to acknowledge the assistance given to him by several firms, who readily placed their experience at his disposal, and to many of his colleagues who assisted him in the preparation of the paper.

Some Notes on Recent American Blast-Furnaces*

By T. H. Stayman†

At the South Works of the Carnegie-Illinois Steel Corporation, South Chicago, Illinois, two large blast-furnaces designed and built by the Arthur McKee Co., have the following lines :

	Ft.	In.
Hearth dia.	28	0
Bosh dia.	31	0
Stockline dia.	21	6
Large bell dia.	16	6
Height (centre-line of iron notch to top ring casting)	108	0

Each of the two furnaces is rated at a production of 1,500 tons of pig iron per day. As these two furnaces are identical, they will be referred to throughout the paper as furnace *D*.

The following figures give the lines of furnace *D* and of three other recent furnaces :

	A. Ft. In.	*B.* Ft. In.	*C.* Ft. In.	*D.* Ft. In.
Hearth dia.	25 9	25 0	25 0	28 0
Bosh dia.	28 9	28 0	28 0	31 0
Stockline dia.	20 0	19 6	19 6	21 6
Large bell dia.	15 0	14 6	14 6	16 6
Height	103 11	100 0	100 3½	108 0
Number of tuyeres ...	16	16	14	20
Bosh angle	81°—28 ft. 9 in.	81°—28 ft. 9 in.	81°—28 ft. 9 in.	81°—40 ft. 27 in.
Bell operation	Electric.	Electric.	Electric.	Air.

Stack

Furnace *D* has a stack constructed with a minimum plate thickness of 1 in., but the bottom tier of plates is 1¼ in. thick and the top tier and dome are 1⅛ in. thick. The whole of the stack is electrically welded.

The lintel is of flat plate construction, suitably stiffened by large angles. This form is adopted in all the furnaces referred to above, but the lintel in furnace *D* is electrically welded.

Hearth (Furnace D*)*

Two courses of carbon blocks are laid in the hearth, these are numbers 2 and 3 starting from the top and give a depth of 3 ft. 9 in. of carbon for the two courses. The hearth wall, from the top of the carbon blocks to a level 3 in. above the top of the hearth jacket consists of carbon blocks. A carbon filler is used in the voids around the carbon blocks.

The bottom construction of furnace *D* is of the open type, with the hearth jacket exposed and not bricked in.

Furnace Top

In each case the top structure is supported from the furnace top cone through heavy brackets and supports the head sheaves, bell beams, trolleys, and platforms.

Furnaces *A*, *B*, and *C* each have a 45-ton trolley, and furnace *D* has a 75-ton trolley capable of handling the large bell and hopper together.

The revolving distributors are of McKee design, furnaces *A*, *B*, and *C* having manganese-steel small bells, while furnace *D* has a cast-stee small bell, 7 ft. 0 in. in dia., with wearing plates of manganese steel. Each distributor has three top rollers, three bottom rollers, and three side rollers.

The large bells have a slope of 53° and are rigidly attached to the bell rod by means of a stiffening cone and a bushed socket joint. By this means, and by directing the upper end of the rod in a straight line vertically, the axis and travel of the bell in opening is always plumb.

Lubrication

An automatic, centralized, lubricating system is provided for the furnace-top structure and also

* Received 29th November, 1946.

† Messrs. Head, Wrightson & Co., Ltd., Thornaby-on-Tees.

for the skip hoist. The bearings are greased at intervals by means of an automatic timer and a motor-operated grease pump.

Skip Bridges

Each skip bridge is supported at its lower end by foundations at the skip pit, and at its upper end by the furnace stack. Both supports are through pin connections.

The bridges are of the through-truss type with a double track, the underside of the incline being enclosed by $\frac{5}{16}$-in. steel deck plate. Idler sheaves for skip and bell ropes are carried by the bridge.

Skip Hoist

Two skip cars of the bail type are provided for each furnace, the skip cars in furnaces *A*, *B*, and *C* each being of 200 cu. ft. capacity, while the cars in furnace *D* are each of 300 cu. ft. capacity. Each hoist consists of a single rope drum, grooved to receive two twin ropes, one pair winding over and one pair winding under. In the case of furnace *D* the hoist is driven by two 212-h.p. motors.

The skip car weighs 22,000 lb. and this, together with a maximum ore load of 40,000 lb., can be hoisted at a speed of 350 ft./min. With only one motor the hoist is capable of handling the full load at a reduced speed.

The total length of skip travel is 224 ft. and the inclination of the skip track is 55° with the horizontal.

Hoist House

Located in the hoist house are the skip hoists, bell hoists, automatic stockline recorders, and motor-generator sets for variable voltage control of skip motors. A monorail track with a roller-bearing trolley and a 5-ton hoist is provided for handling the equipment in the building. This track extends through the doorway.

Each hoist house is equipped with a ventilating and air-filtering unit having sufficient capacity to maintain a temperature not exceeding 110° F. inside when the temperature outside is 100° F. ; and a heating capacity to maintain a temperature of 60° F. inside when the temperature outside is 0° F. Outside air entering the building is cleaned by the use of rotoclones and electrostatic cleaners having over 90% efficiency. Positive air pressure is maintained inside the house to prevent infiltration of dirt.

The bell hoists for furnaces *A*, *B*, and *C* are electrically operated and for furnace *D* are of the pneumatic type using air at a regulated gauge pressure of 15 lb./sq. in. Operating air is obtained from either the furnace cold blast or from plant compressed air.

There is a good deal of debate on the question of electrical *versus* air operation for the bells. The air cylinder has the advantage of being both a bell hoist and a counterweight, but because it fulfils a dual purpose it must release tension in the cable before the bell opens, and for this reason air hoists are used in conjunction with bell beams. The raising of the cylinder lowers the bell. The cylinders are of large size designed to work at low pressure, and are operated from the cold-blast system or plant compressed air in an emergency. The large bell cylinder has relief valves on each side of the cylinder, allowing the cylinder to move under extreme shock and taking care of explosions between the bells. The speed of opening and closing the bell can be controlled accurately and is easily adjusted, smooth operation being assured by the cushioning effect of the air. If positive opening is required an electric hoist should be used and in this case a balance weight is necessary to close the bell. The bell rod is carried by a quadrant in such a way that the shock is not excessive when the bell closes.

Two automatic stockline recorders are provided for each furnace. These are placed at 90° to the tap hole to measure and record the height of the stock in the furnace.

In addition to the automatic rods, one manually operated rod is provided for each furnace.

Cast House—Furnace D

At each cast house, the roof in the first bay is removable so that the large bell and hopper may be lowered from the furnace top by means of the 75-ton top trolley. A 25-ton cast-house crane can handle the large bell and hopper castings when they have been lowered into the cast house.

Each cinder-notch stopper is water-cooled and furnished with an air-operated stopper mechanism ; they are designed to raise up when out of the notch.

The stationary pedestal-type clay guns are electrically operated through remote controls and are capable of plugging the tapping holes against full blast pressure. The clay capacity is 12 cu. ft. Remote-control pulpits for operating the clay guns are erected in an elevated position to afford the operator an unobstructed view of the tapping hole.

Several types of clay guns are in use, most of them being already known in England, but the latest development is an electro-hydraulic gun. This gun may be pedestal- or column-mounted and has two operating cylinders. One cylinder, located on the boom, swings the gun into and out

of the tapping hole by means of a rack actuated by the piston and travelling on a stationary gear. The other cylinder is of the plain piston type and feeds the clay into the tapping hole.

The equipment is operated by a 40-h.p. motor driving two 30-gal./min. pumps, one pump being mounted on each end of the motor shaft. All motions are controlled by two four-way electric solenoid-operated valves, one mounted on the gun and the other on the boom, with all valve and motor controls mounted on the wall inside the cast house.

Iron runners are provided to accommodate eight 75-ton capacity ladles at each furnace. Slag will normally be run to the slag pit and granulated by means of a stream of water, but if desired it can be diverted to five 200-cu. ft. capacity slag ladles at each furnace.

Stockhouse

Coke is automatically drawn from central coke bins, screened, weighed, and charged into the skip cars at the proper points of the charging sequence by the fully automatic coke-charging control. All other materials must be drawn from the bin gates in the stockhouse, and as this calls for the handling of upwards of 3,000 tons/24 hr. (much more in the case of furnace *D*) a great deal of consideration is given to the equipment to handle it.

The choice lies between mechanically operated or hand-operated gates.

The advantage of mechanically operated gates is that they involve less physical labour for the scale-car operator, but in speed of material handling and accuracy of measurement there is little to choose between the two types. The maintenance of mechanical gates is higher than that of hand-operated gates and a motor or drive failure will incapacitate an entire stockhouse. A recent development which has improved the performance of hand-operated gates consists of the installation above the gate of a flexibly supported channel member which can be deflected by a sharp opening of the gate. When the channel deflects, it breaks any loose material which tends to bridge across the bottom of the bin or the gate. For these reasons furnaces *A*, *B*, *C*, and *D* are fitted with hand-operated bin gates in the stockhouse.

Located in the stockhouse at each furnace is a stock-watering device which adds to each skip of ore a pre-selected quantity of water. This device is electrically interlocked with the charging control so that the ore loads automatically receive any quantity of water from 0 to 200 gal. in 20-gal. increments as determined beforehand by the setting of a dial.

Stoves

Three two-pass side combustion stoves are included with furnace *D*, each 26 ft. 0 in. in dia. by 123 ft. 6 in. high. The checkers have $1\frac{15}{16}$-in. sq. openings with $1\frac{1}{4}$-in. walls to give a total heating surface of 250–300 sq. ft.

The combustion chamber has a cross-sectional area of 56 sq. ft. and is constructed with a 9-in. skin wall of super-duty brick laid in high-temperature cement.

The grids for supporting the checkers are of special alloy iron and are designed to support the superimposed loads at temperatures up to 800° F. The bottom slab which supports the cast-iron columns is of lumnite cement, 15 in. thick, and reinforced with steel bars.

Each stove has a 25,000-cu. ft./min. gas burner with a motor-driven fan to supply air for combustion and these, together with other blast-furnace instruments, are located on a stove-operating platform at the same level as the cast-house floor. This simplifies the tending of the stoves by eliminating the complications of two operating levels.

The whole of the stove casing is electrically welded.

The material used for stove columns is cast iron, but the girders are made to the following specification :

C, %	... 2·95–3·00	P, %	... 0·20 max.
Si, %	... 1·75–2·00	Ni, %	... 1·00 min.
Mn, %	... 0·75–1·00	Cr, %	... 0·30–0·50
S, %	... 0·12 max.	Mo, %	... 0·35–0·50

This gives a non-growth iron with a tensile strength of 50,000 lb./sq. in. and is suitable for use at a working temperature of 800° F.

Mixer Lines and Hot-Blast Control

A separate mixer line equipped with a 28-in. sliding plate valve is connected to the base of each hot-blast trunk and to the 36-in. dia. mixer-air header. For regulating the mixer air, a 36-in. butterfly valve is located in the header and operated by the power unit of the hot-blast control. The power unit has a declutching arrangement for hand control. The hot-blast controls operate the butterfly valves admitting the required amount of cold blast to the hot-blast main and maintain a uniform temperature of the hot-blast to the furnace. Each control is so designed that after the cast has been completed the control may be set by the operators at 800° or 900° F., and it then automatically advances

the temperature of the blast at a rate of 100° F. every 15 min. until reaching a temperature which has been previously set by the operator. After reaching this point, it maintains the desired blast temperature without attention by the operator.

Uptakes and Downcomer

Four offtakes on each furnace converge into two vertical risers which join into one downcomer. All these mains are of $\frac{1}{2}$-in. plate and are lined with $\frac{1}{2}$-in. thick 0·6% carbon-steel plate.

At the connection with the furnace casing the offtakes are elliptical in form. This increases the area of the offtake and also the furnace perimeter covered by the offtake.

Dustcatchers

With the single downcomer the gas is led into the centre of the top cone of the dustcatcher and through an expanding nozzle which extends vertically into the dustcatcher. This nozzle has an included angle of 8–10°. As the gas reaches the bottom of the nozzle it turns upwards into the space between the nozzle and the dustcatcher chamber and passes out of the top of the dustcatcher through an annular passage around the expanding nozzle. The gas flow changes its direction at the bottom of the nozzle and at this point of minimum velocity the heavier particles of dust are deposited, ample space being provided for the dust to accumulate in the bottom cone of the dustcatcher. Dustcatchers of this type working successfully on 26 ft. 0 in. hearth furnaces are 30–35 ft. in dia. with a straight side of 35 ft. 0 in. to 40 ft. 0 in.; they remove upwards of 60% of flue dust from the blast-furnace gas.

The dustcatcher for furnace *D* will be 38 ft. 0 in. in dia. with a 40 ft. 0 in. straight side. The shell will be of welded construction, insulated on the outside by 2 in. of magnesia block, weatherproofed by a covering of asbestocite, a tough, non-inflammable sheet.

Dry centrifugal cleaners have frequently been used for secondary cleaning of hot gas for boilers, efficiencies of 90% being obtained from some installations. It appears safe to assume that an amount of dust equal to half that caught in a dustcatcher can be removed in a centrifugal. Unless there is some need for additional dry dust, it is not necessary to install a centrifugal ahead of a wet washer where the sludge is being reclaimed from the washer overflow. In the latter case the dust will be caught in the wet washer without adding to the load on the washer.

Primary Gas Washers

Wet washing of gas in a single-tower scrubber has been tried at many plants and it has been found that an installation which gives satisfactory results at one plant has produced decidedly poorer results at another plant under different furnace conditions.

The original static tower washers have been improved by the introduction of low-head recirculating pumps in the form of rotors in the bottom of the washing tower, thus giving a more intimate contact between gas and water before the gas reaches the hurdles or tile baffles. This, in many cases, has removed the difficulties of plugging both the hurdles and the washer bottoms and has reduced the water consumption from 30 to 20 gal./1,000 cu. ft. of gas.

One engineer has developed a stationary disintegrator washer where the water is sprayed through nozzles at a pressure of 150–200 lb./sq. in. He is willing to guarantee a gas cleanliness of 0·015 grains/cu. ft. and has had results as good as 0·005 grains/cu. ft. The amount of water used is 28–30 gal./1,000 cu. ft. of gas and the operating cost is the cost of pumping the water, half of which is required at 150–200 lb./sq. in. and half at 10–12 lb./sq. in. This cost varies with the pumping cost, but at one plant it was 5–6 cents per ton of iron.

The pressure drop through the cleaner is 22–30 in.

Fine Gas Cleaners

The choice between disintegrators and precipitators for fine cleaning must be made on consideration of capital cost and operating cost. Generally the installation cost of a disintegrator is less than that of a precipitator for the same work, but the operating cost is considerably higher. There are other factors to be taken into account in choosing between the two types of equipment. The disintegrator is capable of boosting, of flexibility in regulating efficiency, of simple and easily maintained adjustments, and of consistent performance under wide fluctuations of inlet loads. Against these are the disadvantages of higher maintenance, higher water consumption and operating costs, and the danger of producing a negative pressure in the gas system in case of a sudden loss of gas pressure at the disintegrator inlet.

The precipitator has the advantage of smaller water consumption, a minimum number of moving parts, low gas-friction losses, and low operating costs, but its adjustments are difficult to maintain and its efficiency is not constant under severe conditions of inlet loading; its flushing water must be relatively clean and the cost of protecting its wetted surfaces is high if corrosive water is to be used.

As furnaces and auxiliaries are enlarged on existing sites, space requirements play an increasingly large part in the design and choice of equipment. For this reason precipitators have been superimposed on primary washers with excellent results.

This type of installation is not cheaper than one where the precipitator is placed on the ground, but it has the advantage of reducing the ground space required.

A plant of three of these units has the rating shown in Table I.

TABLE I

	Gas Volume 235,000 cu. ft./min.		Gas Volume 210,000 cu. ft./min.	
	3 units.	2 units.	3 units.	2 units.
Inlet dust loading, grains/cu. ft. ...	0·25	0·25	0·15	0·15
Efficiency, %	95	85	96–87	87·90
Outlet dust loading, grains/cu. ft. ...	0·125	0·375	0·006–0·008	0·027–0·025

Slag

The slag is handled either into a slag pool or by large ladles, generally of the air-dump type. In the former case the slag is run into the pool, where it is granulated by a stream of water and later removed by grabs or dumpers.

The air-dump slag ladles are of large size—up to 400-cu. ft. capacity—and are of cast steel or cast iron. The cars for carrying these ladles are constructed mainly of cast steel and are approximately 23 ft. 0 in. over the buffers and 11 ft. 0 in. wide, the height with the ladle in position being 11 ft. 0 in. The weight of the car is 28 tons and of the ladle 11 tons.

In order to conserve space a special car carrying two 400-cu. ft. ladles is built with a length over buffers of 37 ft. 9 in.

Hot Metal

In some cases plant lay out and levels fix the size and type of hot-metal ladles, but a considerable number of mixer-type ladles are in use. For a ladle of 175 tons capacity the size is 53 ft. 2 in. over buffers, 12 ft. 11½ in. high, and 10 ft. 8½ in. maximum width.

It is claimed that the heat loss in the iron is less than with any other type of ladle and the iron loss due to skulls is small.

Sintering

Fig. 1 shows the increase of sintering capacity from 1941 to 1944 when the total sintering capacity amounted to 25,000,000 tons per year. In four years the capacity increased from 13,000,000 to 25,000,000 tons, and this appears to demonstrate that sintering is the finest method of agglomerating fine ores for use in the blast-furnace.

The materials used in the sinter are fine ores, flue dust, roll scale, or other fine ore-bearing materials, and the aim is to produce a material with a uniform cell structure which will break up by handling but which will have enough stability to support a furnace burden.

An item of interest is the rotary cooler which takes the sinter from the discharge end of the strand and cools it until it can be handled by a rubber belt. This cooler consists of a rotating table with an annular **V**-shaped trough at its circumference, the outer wall of which is stopped

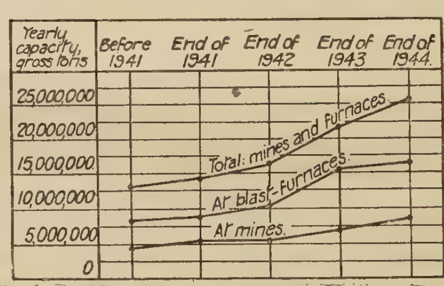


FIG. 1—Increase in sintering capacity from 1941 to 1944 (Morgan[3])

some distance short of the table. The sinter is charged into the trough and can be cooled by blowing air through louvres in the inner wall of the **V** or by light water sprays if desired. When cool the sinter can be ploughed off and conveyed by rubber belt to the stock bins.

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2. B. B. FROST: *Iron and Steel Engineer*, 1943, vol. 20, Oct., p. 54.
3. M. F. MORGAN: *Steel*, 1945, vol. 117, No. 14, p. 132.

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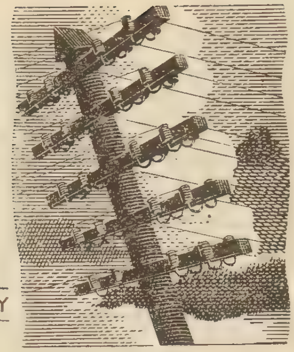


ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Meetings 1947

ANNUAL GENERAL MEETING

The Annual General Meeting of the Iron and Steel Institute will be held in London, on Wednesday, 14th to Friday, 16th May, 1947. The meeting will be opened by the presentation and discussion of a Symposium on Hardenability (to be published as Special Report No. 36, *see* notice below). Official business will be considered in the morning of the second day, Thursday, 15th May, and will be followed by two sessions for the reading and discussion of papers.

On the third day a final session in the morning will be devoted to the reading and discussion of further papers.

A Dinner for Members will be held at the Connaught Rooms on the evening of the second day, Thursday, 15th May.

A number of invitations to attend the meeting is being sent to European members.

AUTUMN GENERAL MEETING

Preliminary arrangements have been made to hold the Autumn General Meeting of the Iron and Steel Institute in London, on Wednesday and Thursday, 12th and 13th November, 1947.

SUMMER MEETING IN SWITZERLAND

At the invitation of the Swiss steel and engineering industries, a Summer Meeting of the Iron and Steel Institute is being held in Zurich. Arrangements for the visit are now being made and a further announcement will give details of the programme. The provisional dates are from Tuesday, 8th, to Wednesday, 16th July, 1947, with extensions to Monday, 21st July.

SYMPOSIUM ON POWDER METALLURGY

To give prominence to recent progress in Powder Metallurgy, a Symposium of papers on the subject, covering both ferrous and non-ferrous metals, has been arranged for the afternoon of Wednesday, 18th June, 1947, continuing during the whole of the following day, Thursday, 19th June.

The selection of papers is now in progress and a further announcement will be made.

Joint Conference on Desulphurization and Dephosphorization, with particular reference to Cupola Iron

Organized by the Institute of British Foundrymen in collaboration with the Iron and Steel Institute, a conference on this subject will be held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 19th March, 1947.

The object of the meeting is to discuss work already done before undertaking further researches and as this will involve both founding and steelmaking interests, Members of the Institute are cordially invited to attend.

Special Report No. 36

" SYMPOSIUM ON THE HARDENABILITY OF STEEL "

An account of research organized by the Technical Advisory Committee of the Special and Alloy Steels Committee (Ministry of Supply) and published by the Iron and Steel Institute.

This Special Report, which will be presented and discussed at the Annual General Meeting on May 14th to 16th, 1947, is now in the printer's hands.

*The Report will be available to Members for sale only, at the reduced Member's rate of 10*s. *each (published price 16*s.*). Order forms will be circulated and Members wishing to purchase copies are requested to return the Order Forms to the Secretary as soon as possible.*

In 1943 a small mission of British metallurgists visited the United States and Canada to discuss the conservation of critical alloying elements and the development and testing of alternatives to the high-alloy steels. More work had been done

in the United States on the Jominy end-quench hardenability test and on the addition of boron to steel than in Great Britian, and it became evident that an organized research on the value and application of the Jominy test should be immediately undertaken. When the mission returned, a Sub-Committee of the Technical Advisory Committee was set up with the following terms of reference :

(a) To standardize the conditions of carrying out the end-quench (Jominy) hardenability test, examine the effect of deviation from the standard conditions, and adopt a standard method of reporting the data.

(b) To examine the fundamental principles governing the test and recommend the best methods of interpreting the results of the hardenability curve.

(c) To survey a representative set of *En* steels by hardenability tests and correlate the results with the full mechanical properties in the light of the presently adopted use of these steels as set out in Table 2 of *B.S. 970*.

A great amount of investigation into the basic principles of the end-quench hardenability test has been carried out and a full account of this work is presented in this Special Report of 420 pages, which, in addition to the introductory matter and the bibliography of 255 references, comprises 20 papers. Summaries of the papers will appear in the abstract section of the *Journal* as soon as the Report is ready.

Professor A. M. Portevin

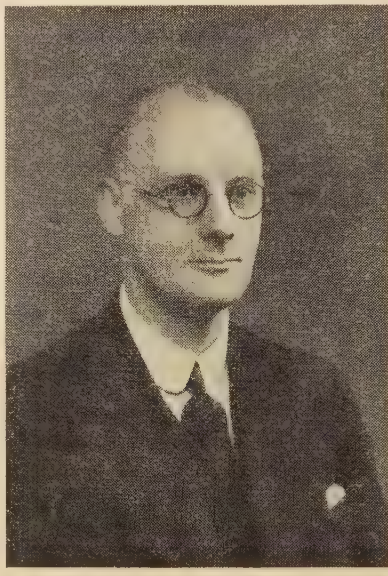
In appreciation of his outstanding contributions to the knowledge of Metallurgy, the Council has nominated Prof. Portevin to be an Honorary Member of the Iron and Steel Institute.

For many years Professor at the *Ecole Centrale des Arts et Manufactures*, Paris, M. Portevin has a long connection with the Institute. After receiving a Carnegie Scholarship award and Carnegie Gold Medal in 1907, he was elected a member of the Institute in 1910, and at the Annual Meeting in 1936 he was present to receive the Bessemer Gold Medal. In 1942, he was elected a Fellow of *l'Académie des Sciences*.

Prof. Portevin's most notable contributions to the science of metallurgy have been in the field of heat-treatment where he is acknowledged to be one of the greatest experts. His activities have covered investigations on many other subjects and particularly in the metallurgy of welding.

Staff Biography No. 1

Mr. Alan E. Chattin, Assistant Secretary and Technical Editor, was born in 1892. He was educated in England, France, and Germany, matriculating in 1908. After being articled to a general analytical chemist, he served with Messrs. Johnson and Sons, smelting works, until the outbreak of war. On being invalided out of the army in 1916, he rejoined Messrs. Johnson and Sons, and in 1923 joined the staff of Messrs. D. C. Griffiths and Company, metallurgical chemists. In 1925, he was appointed Assistant Secretary of the Iron and Steel Institute, and, later, also Secretary of various Research Sub-Committees. He served also as Assistant Secretary of the Institute of Metals for a period during 1945–46, pending the return from active service of Lieut.-Colonel S. C. Guillan.



From the time of his appointment as Assistant Secretary, Mr. Chattin also served as Assistant Editor, and in 1945, Executive Editor, and in these capacities he was responsible for the production of the Journal of the Iron and Steel Institute. Since July 1946, he has served as Technical Editor.

Mr. Chattin's technical education was obtained with the Sir John Cass Technical Institute, where he studied from 1919 to 1923, taking his B.Sc. (London) in Pure Science. In 1926, he obtained his B.Sc. (Hons.) (London) in Metallurgy. He is a Fellow of the Institution of Metallurgists and an Associate of the Royal Institute of Chemistry.

THE IRON AND STEEL ENGINEERS GROUP

Programme of Meetings—1947

The **First Meeting** of the Group was held on Wednesday, 16th October, 1946. Mr. W. F. Cartwright was in the Chair, and Dr. C. H. Desch, F.R.S., President of the Iron and Steel Institute, was present at the opening of the Meeting. One hundred and fifty people attended the discussions,

and a Buffet Luncheon was served in the Library during the Meeting. No formal papers were read, but three speakers introduced each session before the subjects were open to general discussion.

In the morning session, the subject discussed was "*Steelworks Locomotives—Diesel versus Steam.*" A report of the discussions is contained on pages 87 to 106.

The afternoon session was concerned with "*A.C. and D.C. Drives for Steelworks Cranes and Ore Bridges*" : the opening speakers were Mr. L. Rothera (Colvilles Ltd.), who spoke from the users' point of view, Mr. J. Russell-Taylor (Igranic Electric Co. Ltd.), who spoke, instead of Mr. R. West, from the manufacturers' point of view, and Mr. J. P. Parker, (McLellan and Partners Ltd.), who advocated "Ward Leonard Control". The discussions at this session will be published in the February issue of the *Journal.*

The **Second Meeting** of the Group, with Mr. W. F. Cartwright in the Chair, was held on Wednesday, 11th December, 1946. In the morning the Meeting discussed a paper by Mr. H. J. Knight, (Shell Oil Company Ltd.), on "*Lubrication in Iron and Steelworks Engineering*". In the afternoon, an open discussion was held on "*Roll-Neck Bearings*".

A Buffet Luncheon was held in the Library in connection with the Meeting. A full report of the Meeting will appear in the March issue of the *Journal.*

The **Third Meeting** of the Group will be held at 4, Grosvenor Gardens, S.W.1, on Wednesday, 26th February, 1947, and will be devoted to the presentation and discussion of three papers on the engineering aspects of "*The Blast Furnace of Today*". These papers appear on pages 107 to 140 of this issue. A circular notice about this Meeting has been sent to all members of the Group.

THE BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Steel Castings Research Committee

In collaboration with the Iron and Steel Institute, a meeting is to be held on Thursday, 20th March, 1947, to discuss the First Report of the Side Blown Converter Practice Sub-Committee (*see* this issue p. 33), and the First Report of the Converter Refractories Sub-Committee (to be published in the February *Journal*).

Further details will be announced.

NATIONAL CERTIFICATES IN METALLURGY

The Joint Committee for National Certificates in Metallurgy has reported progress on the Scheme for the award of National Certificates in Metallurgy. The Scheme, under the aegis of the Iron and Steel Institute, the Institution of Mining and Metallurgy and the Institute of Metals, working in co-operation with the Ministry of Education, has been successfully launched and the Pass List for the Senior Part-time Course for Ordinary National Certificates has been published for the year 1945/1946.

Schemes submitted by the following Examining Bodies have been agreed :

City and Guilds of London Institute—The Joint Committee has agreed that Courses of study, based on the content of the scheme in the Principles and Practice of Metallurgical Operations, as submitted by the City and Guilds of London Institute, are suitable for submission to the Ministry by Colleges and Schools, under the arrangements and conditions governing the award of National Certificates in Metallurgy.

East Midlands Educational Union, Northern Counties Technical Examinations Council, Union of Lancashire and Cheshire Institutes—

The Schemes submitted for a Senior Course, leading to an Ordinary National Certificate, have been agreed as suitable for submission to the Ministry by Colleges and Schools.

Schemes submitted by the following Technical Colleges for a Senior Course have been approved :

Battersea Polytechnic, London ; Birmingham Central Technical College ; Chesterfield, Coventry, Cumberland (Workington), Enfield, and Newport Technical Colleges; Dudley & Staffordshire Technical College (Scheme supplementary to the Scheme of County Technical College, Wednesbury); Rutherford College of Technology, Newcastle ; County Technical College, Wednesbury.

Final Examinations have been held, this year, at the following Colleges : *Birmingham, Cumberland, Rutherford and Wednesbury,* and although the Committee regards it as premature, in view of the small number of candidates in the initial year, to make any authoritative comment on the results, it has drawn some conclusions from the reports of the Assessors, to which it draws the attention of Teachers and Students. These are that, although great accuracy in technical language is not looked for at this stage, clear expression in ordinary language ought reasonably to be expected, and greater neatness and accuracy in drawing of diagrams. Also that students should supplement lecture notes with more reading of suitable text books and, where possible, should be given an opportunity of seeing for themselves some of the metallurgical operations which they are called upon to describe, when these are not involved in their daily work.

INSTITUTION OF METALLURGISTS

Appointments Register

Under Licence of the London County Council, an Appointments Register, organized by the Institution, is to commence operation in January, 1947. The Register is designed to provide contact between members of the Institution seeking posts and employers having vacancies on their metallurgical staffs.

In order that the scheme may operate successfully employers are invited to send to the Institution particulars of vacancies for qualified metallurgists. Lists of vacancies, whether notified by employers or otherwise advertised, will be circulated at frequent intervals to members whose names have been submitted for inclusion in the Register.

All enquiries should be addressed to the Registrar, Appointments Register, Institution of Metallurgists, 4, Grosvenor Gardens, London, S.W.1.

TRANSLATION SERVICE

Since the announcement made in Circular No. C. 692 on December 28th, 1946, further translations have been put in hand and the following are now available or in course of preparation.

Translations Available

No. 295 (German). E. Siebel: "The Technical Mechanism of Plastic Deformation." (*Archiv für das Eisenhüttenwesen*, 1944, vol. 13, July-Aug., pp. 13-22.)

No. 296 (German). G. Becker, K. Daeves, and F. Steinberg: "Protection against Corrosion by Chromium Diffusion Zones." (*Zeitschrift des Vereines deutscher Ingenieure*, 1941, vol. 85, Feb. 1, pp. 127-129). (Translated by Mr. W. B. Jones and made available through the courtesy of Tube Investments Ltd.)

No. 297 (German). E. Siebel and G. Hahn: "The Creep of Heat-Resisting Steels at Temperatures of 800 to 1200° C." (*Archiv für das Eisenhüttenwesen*, 1944, vol. 17, Mar.-Apr., pp. 211-220). (Translated by Mr. D. G. Boxall and made available through the courtesy of the National Gas Turbine Establishment, Ministry of Supply.)

No. 298 (Swedish). A. Hultgren: "The Origin of Silicate Inclusions in Basic Arc Furnace Steel." (*Jernkontorets Annaler*, 1945, vol. 129, No. 11, pp. 633-671). (Translation provided through the courtesy of the author and Jernkontoret.)

No. 299 (Swedish). A. Norrö and S. Lundquist: "The Miscibility Gap in the Fe-S-C System at Carbon Saturation in the 1300-2000° C. Temperature Range. (*Jernkontorets Annaler*, 1946, vol. 130, No. 3, pp. 118-126.)

Translations in Course of Preparation

(German). H. Bennek, W. Koch, and W. Tofaute: "The Production of Chromium Coatings by Diffusion." (*Stahl und Eisen*, 1944, vol. 64, Apr. 27, pp. 265-270). (Translated by Mr. W. B. Jones and made available through the courtesy of Tube Investments Ltd.)

(German). W. Lueg and A. Pomp: "Tests to Determine and Predict the Drawing Force in the Bright-Drawing of Steel." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1944, vol. 27, No. 4. pp. 43-52.)

(Swedish). S. Mörtsell: "Rationalization in Swedish Iron-Ore Dressing." (*Jernkontorets Annaler*, 1946, vol. 146, No. 9, pp. 369-460.)

(Swedish). R. Tosterud and E. Stenfors: "Investigation of the Wear of Rolls during the Hot-Rolling of Wire and Strip." (*Jernkontorets Annaler*. 1946, vol. 130, No. 6, pp. 213-238.).

(German). H. Unckel: "Phenomena in the Pressing of Metal Powders." (*Archiv für das Eisenhüttenwesen*, 1945, vol. 18, Jan.-Feb., pp. 161-167.)

Charges for Copies of Translations.—For the above translations a charge will be made of 10*s*. for the first copy and 5*s*. for each additional copy of the same translation. Requests for translations should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

Translations Prepared at Members' Request.—Members requiring translations of foreign technical papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK REVIEWS

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

FUEL—PREPARATION, PROPERTIES AND USES

Progress in Industrial Fuel Practice. R. J. Sarjant. (Fuel Economy Review, 1946, vol. 25, pp. 33–37). A brief account is given of the changes which have taken place in the use of industrial fuel since the need for economy in consumption arose as a result of the first World War. The three major factors which have helped to bring about these changes are: (1) Research into properties of fuels and plant conditions; (2) the raising of the standard of plant operation; (3) the use of modern and efficient types of plant. This last factor is capable of bringing about the greatest economy when properly applied, as is shown in the iron and steel industry.

The Need for a Practical Classification of British Coals. G. C. Allfrey. (Fuel Economy Review, 1946, vol. 25, pp. 83–85). The lack of uniformity in the combustion characteristics of British coals is discussed. Variations in the sizing of coal and its chemical and physical constitution are the source of great difficulty to fuel engineers. Consistency of quality can only be achieved if a standard system of size classification is adopted, and a simple practical relationship is established between the type of a coal and its behaviour on combustion, irrespective of its chemical composition and source.

The Future of Pulverized-Coal Firing in Great Britain. C. H. Sparks. (Institution of Electrical Engineers and Institution of Mechanical Engineers, Joint Meeting, Dec., 1946, Preprint). A short account is given of the preparation and use of pulverized coal in Great Britain and the United States. The variable quality and increasing quantity of ash present in such fuel are the main problems to be overcome in its use. Liquid ash-removal and the use of specially selected coal are successful to some extent, but the fine dust which is always present in the gases must be removed, often with difficulty and expense. To solve this problem, the cyclone furnace has been evolved in the United States, where a method of overfeed firing with moving grates suitable for power-station installations has also been developed. It is likely that pulverized-coal-fired boilers will remain in demand to dispose of the output of dust resulting from the increasing mechanization of the mines unless a profitable means of upgrading is found.

Study of Slanting Type Didier Coke Ovens, Stadische Werke, Karlsruhe. (British Intelligence Objectives Sub-Committee, 1945, F.I.A.T. Final Report No. 566: H.M. Stationery Office). A report is presented of a visit to the municipal carbonization plant at Karlsruhe. Gas, coke, tar, and benzene are manufactured from coals from the Saar, Ruhr, and Eschweiler districts. There are three batteries of sloping Didier gravity-discharging coke-ovens. As the coke is discharged by gravity there is no need to provide space for a pushing machine beside the battery. A poor coking coal can also be carbonized because the weak coke, which could not be discharged from horizontal ovens with a pusher, can be discharged by gravity with little trouble. Descriptions of the Didier ovens are given with sketches.

Potash Reclamation. A. G. Arend. (Chemical Age, 1946, vol. 55, Nov. 9, pp. 565–568). A brief account is given of the recovery, as by-products, of the potassium salts present in blast-furnace flue dust. With the electrostatic precipitation process at Skinningrove, it is possible to recover upwards of 100 lb. of potassium chloride per million cu. ft. of gas.

Gas Utilization. (Iron and Steel, 1946, vol. 19, Nov., pp. 605–607). A description is given of the scheme adopted for the integration of the fuel supplies at the iron and steel works at Tollcross, Glasgow. Throughout the two works consumption points are equipped to utilize either blast-furnace or coke-oven gas; the distribution of these gases is controlled from a central panel by a fuel engineer.

Industrial Uses of Fuel Oil. (Fuel Economy Review, 1946, vol. 25, pp. 22–32). A review is made of the possible channels of development in the use of liquid fuels in the iron and steel, non-ferrous metal, and ceramic industries. Oil is the cheapest form of easily controlled fuel, and holds, from the economical standpoint, a position midway between electricity and town's gas on the one hand, and solid fuels on the other. Indiscriminate conversion from the burning of coal to the burning of oil is not desirable economically, since in some instances, *e.g.*, in boiler installations, the saving in the quantity of fuel used is negligible. Oil firing is most advantageous in conditions where its auxiliary advantages, such as cleanliness, are important. To obtain the maximum efficiency, the conditions of combustion of oil must be very carefully controlled.

REFRACTORY MATERIALS

Refractory Materials and Fuel Economy. G. R. Rigby. (Iron and Coal Trades Review, 1946, vol. 153, Oct. 25, pp. 717–721). This paper was presented at a conference on "Fuel and Power" sponsored by the Ministry of Fuel and Power.

The factors governing the selection of refractory materials for iron- and steel-making furnaces are discussed in relation to fuel economy, special reference being made to heat losses in refractory installations, furnace design, desirable properties, disintegration by the action of slags and gases, and the choice of bricks for regenerators and recuperators.

Modern Refractory Practice. T. Firkin. (Mechanical Engineers' Association: Australasian Engineer, 1946, Sept. 7, pp. 73–77). Progress in the manufacture and properties of industrial refractory materials during the last 20 years is reviewed.

The Durability of Refractory Materials in the Carbonising Industry. E. Heaton, F. H. Clews, and A. T. Green. (Institute of Fuel Bulletin, 1946, Oct., pp. 27–34). The properties of silica material (containing over 92% of silica), siliceous material (containing 78–92% of silica), and firebrick material are reviewed and the principles involved in the attack of slagging agents and alkalies on refractories are explained in the first part of the paper. In the second part the failures occurring in vertical retorts, horizontal retorts, and coke ovens are considered.

The Behaviour of Quartz in Fireclay Refractories. J. Sharp Smith and P. F. F. Clephane. (Institution of Gas Engineers, 1946, Nov., Communication No. 305). An illustrated description is given of an investigation into the behaviour of quartz in fireclay refractories. The materials used were a Stourbridge clay with an abnormal quartz content, an artificial fireclay-quartz mixture, and a naturally occurring clay-bonded silica. Test pieces, in the form of 1-in. cubes, were cut and subjected to heat-treatment at various temperatures for periods up to 28 days. Thin sections were prepared at each stage of the heat-treatment and examined microscopically. The refractive index and resistance to thermal shock were also determined for each section. The reaction between quartz and clay leads to the production of glass of low refractoriness, and this change is accompanied by considerable shrinkage.

Mullite appeared to be an end product in all the materials investigated, but it was not formed in sufficient quantity or with sufficient rapidity to stabilize the structure or prevent distortion. The quartz greatly reduced the thermal shock resistance of the refractories. The naturally bonded silica could contain clay in amounts up to 20 per cent. without serious shrinkage, partly because of a compensatory expansion when quartz was converted to cristobalite, and possibly because of the more resistant nature of the quartz which allowed the rate of mullite formation to balance, approximately, the rate of formation of glass from the quartz and clay.

The Reversible Thermal Expansion and Other Properties of Some Magnesian Ferrous Silicates. G. R. Rigby, G. H. B. Lovell, and A. T. Green. (Transactions of the British Ceramic Society, 1946, vol. 45, June, pp. 237–250). A number of compositions in the ternary system MgO–FeO–SiO_2, and two compositions in the quarternary system CaO–MgO–FeO–SiO_2, have been synthesized. These compositions are to be found in the orthosilicate solid solution series, forsterite–fayalite, and in the metasilicate solid solution series, clinoenstatite–FeO.SiO_2. The specimens have been examined in thin section and the optical properties are described. Other data determined include the reversible thermal expansion between 100° and 1,000° C., the specific gravity, and the rates of reduction and oxidation in hydrogen and oxygen respectively. The importance of the magnesian silicates in relation to refractory materials is also discussed.

DIRECT PROCESSES

Treatment of Lean Iron-Bearing Ores. (Iron and Coal Trades Review, 1946, vol. 153, Nov. 22, pp. 919–925). An account is given of the treatment of acid ores of low iron content in the Krupp works at Borbeck by the Krupp-Renn process (*see* Journ. I. and S.I., 1934, No. II., p. 537). The work was carried out on a full-scale plant, with a kiln 50 m. long and 3·6 m. in dia., using a variety of ores and concentrates with iron contents of 18–54%, and a number of different solid fuels. By lining the kiln partly with quartz-schist brick and partly with firebrick, a life of six months was obtained even in the parts subjected to the severest conditions. Pellets produced from Salzgitter ores containing more silica than metallic iron, had a sulphur content of 0·3–0·4%, which could be varied by alterations in the charge and the method of treatment. Part of the total sulphur was removed in the exit gas, which was important when high-sulphur fuels, such as coke made from brown coal, were used. The phosphorus content of the pellets was dependent upon that of the ore, about 70% passing into the iron. The Renn kilns possess two advantages over other tube-furnaces, for, in addition to separating the iron from twice as much silica as is possible with the latter, they also reduce the iron to the metallic state.

Sponge Iron Experiments at Longview, Tex. W. E. Brown. (United States Bureau of Mines, 1946, Report of Investigations No. 3925). Detailed illustrated descriptions are given of tests performed in an experimental furnace for the direct reduction of iron from its ores by natural gas. The ore used in the experiments was mined in east Texas, and contained about 50% of iron, 10% of silica, and 3% of alumina. A large part of the investigation was devoted to the development of a suitable reducing gas from natural gas. The following conclusions were among those reached: (1) In a 25,000-lb. charge, 80% of the iron ore was reduced to metal in 13 hr.; (2) higher degrees of reduction were not obtained because the amounts of carbon dioxide and water vapour present retarded the rate of reaction, and because the exothermic nature of the first stages of the reaction reduced the temperature below the optimum; (3) sintered ore was not reduced as rapidly as unsintered ore; (4) the discharge of the sponge iron was difficult because of sticking; and (5) the sponge, containing 80% of the iron in the reduced state, was easily melted in an electric furnace.

PRODUCTION OF STEEL

The Skoda Works. (Chemical Age, 1946, vol. 55, Nov. 9, pp. 562–563). An account is given of the damage done to the Skoda Works at Pilsen during the recent war, and of the progress made in the reconstruction at this works as well as at some of the branch factories.

Steelmaking Practice. (Steel, 1946, vol. 119, Sept. 23, Supplement). The replies to a questionnaire submitted to American steelmakers indicate that: (1) 51·7% now produce alloy steels in open-hearth furnaces; (2) 32% plan to use basic bricks for open-hearth furnace roofs; and (3) 11% plan to use all-basic linings.

The Operation of Open-Hearth Furnaces with Coke-Oven Gas. D. Kilby. (Journal of the Iron and Steel Institute, 1947, vol. 155, Jan., pp. 3–20). The paper deals with the operation of 100-ton basic open-hearth furnaces at the Redbourn Works of Messrs. Richard Thomas and Baldwins, Ltd., Scunthorpe, which are fired with coke-oven

gas and pitch-creosote. Details of design and construction of furnaces, layout of the pitch-creosote main, design of gas burners and atomizers, operation of furnace, and chief factors affecting smooth working are presented. Typical charges, refractory consumption, a log of a furnace campaign with tonnage of ingots produced, and fuel consumption for a similar period are mentioned. Details of the pitch-creosote mixture are also given.

The Manufacture of Steel in the Acid Open-Hearth Furnace by the Scrap-Carbon Process. B. Yaneske. (Journal of the Iron and Steel Institute, 1947, vol. 155, Jan., pp. 24–26). Because of the scarcity in India of imported hematite pig-iron for operating the pig-and-scrap process in the acid open-hearth furnaces, the author successfully introduced the scrap-carbon process, using 100% of steel scrap, in order to maintain essential supplies of high-grade acid steel. In operating the scrap-carbon process, the deficit of carbon in the charge is made good by the use of petroleum coke, and the deficit in silicon by the addition of acid slag to the molten bath. The furnace hearth is protected from erosion during the melting of the scrap by spreading an easily fusible silica sand over the banks before charging, whilst manganese is introduced into the bath by the employment of manganese ore instead of iron ore for oxidizing the carbon. The history of a nickel–chromium steel heat made by the scrap-carbon process is given as an example, and it is possible to make regularly any composition of steel by the standard practice adopted in India. The quality of the steel manufactured by the scrap-carbon process described is quite as high as that obtained by the pig-and-scrap process. The acid hearths are not destroyed any more by the former than by the latter process, and the average time of heats from tap to tap has not been increased by the adoption of the scrap-carbon process. The yield of ingots from the metal charged is higher by the scrap-carbon process, whilst no difficulty has been experienced in obtaining the desired tapping temperature of the steel made by this process.

Steelmaking—Notes on German Practice. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 825 : H.M. Stationery Office). Reports are presented on studies of German open-hearth steelmaking practice at nine large works, and on visits to manufacturers of bitumastic ingot-mould lacquers and refractories. It was noted that : (1) Burnt lime is used instead of limestone ; (2) charges are calculated and slag pancakes examined, but no other slag control is practised ; (3) carbometers are not used, the carbon being estimated from the fracture of a bar ; and (4) a bitumen-base lacquer was held to be much better than coke-oven tar for coating ingot moulds.

Melting Rimmed Steel in the Electric Arc Furnace. E. S. Kopecki. (Iron Age, 1946, vol. 158, Sept. 26, pp. 62–65). An account is given of the method developed by the Steel Company of Canada, Ltd., for making rimming steel in a 70-ton basic-lined electric furnace. The power consumption is about 550 kWh./ton of steel and the electrode consumption (the furnace has three 20-in. electrodes) is 12·8 lb./ton of steel.

Quality Control in the Production of Basic Electric Furnace Aircraft and Bearing Steels. W. J. Reagan. (Blast Furnace and Steel Plant, 1946, vol. 34, Aug., pp. 995–1001). Detailed accounts are given of the electric furnace and casting-pit practice for the production of low-alloy steels for aircraft engines and bearings. Logs of typical heats are given.

Survey of the Carbon and Graphite Electrode Industry of Germany. (British Intelligence Objectives Sub-Committee, 1945, F.I.A.T. Report No. 397 : H.M. Stationery Office). The object of the survey was to determine whether the German carbon and graphite electrode industry had developed in any manner which might be of significant interest to the United States industry. Five electrode manufacturing plants, and seven users of electrodes and designers of electrode equipment were visited. Substitutes for the raw material petroleum coke had to be found ; brown coal tar pitch and anthracite tar pitch were used. The conventional Acheson resistance furnaces were used for making graphite. The consumption of graphite electrodes per ton of good steel ingots was about 16–20 lb.

The Determination of Hydrogen in Liquid Steel. J. E. Wells and K. C. Barraclough. (Journal of the Iron and Steel Institute, 1947, vol. 155, Jan., pp. 27–32). A detailed account is given of five methods of sampling the liquid-steel bath which have been used at the Brown-Firth Research Laboratories for the determination of the hydrogen content of liquid steel ; these methods include the use of a water-chilled mould, a cast-iron chill mould, and an ingot sample, in addition to the balloon-tube and notched-pencil methods described by Hatfield and Newell. The methods are compared on different types of steel and conclusions are drawn as to the reliability and

applicability of the methods. The best and simplest method appears to be a modified pencil test in which the sample is taken as soon as possible from the mould and then quenched in water.

FOUNDRY PRACTICE

Foundry and Patternmaking Practice in a Trade School. H. W. Hershey. (American Foundryman, 1946, vol. 10, Sept., pp. 66–72). Ways in which recruits may be attracted into the foundry industry are suggested. An outline is given of a four-year course in foundry work and patternmaking which is based on that in operation at the Revere Trade School, Rochester, New York.

Scientific Measurement in the Foundry. A. Scattergood. (Institute of British Foundrymen: Foundry Trade Journal, 1946, vol. 80, Oct. 17, pp. 155–161). Scientific methods of measuring such quantities as blast volume, temperature, the chilling tendency of an iron, the distribution of grain sizes in sand, human effort, and production costs are discussed, and the use of the data obtained to promote efficiency in the foundry is dealt with.

Correction of Foundry Waste. A. J. Edgar. (Pittsburgh Foundrymen's Association: Foundry, 1946, vol. 74, Oct., pp. 94–95, 168, 174–176). Recommendations for efficient cupola operation are made with data on suitable quantities of bed coke and charge coke for cupolas of different size. A detailed description of cupola operation and control is also given.

The German Steel Casting Industry. (British Intelligence Objectives Sub-Committee, 1945, F.I.A.T. Final Report No. 387: H.M. Stationery Office). A comprehensive report is presented of visits to large, medium, and small steel foundries in Germany, which represent a fair cross-section of the industry. The investigation covered: (1) The type and classification of steel structures produced as castings, (2) the processing methods, (3) the mechanical properties of carbon and alloy cast steels, (4) the type and character of defective castings, (5) the appearance of castings, (6) research work, and (7) plant layout and equipment.

First Report of the Side-Blown Converter Practice Sub-Committee of the Steel Castings Research Committee. (Journal of the Iron and Steel Institute, 1947, vol. 155, Jan., pp. 33–50). Detailed records have been taken of side-blown converter heats from plants of varying design and operating technique. The records have been studied with regard to the composition of metal and slag at various stages of the blow, the temperature increment during the blow, the composition of the exit gas, the effect of variation in tuyere area, the metal loss during blowing, and the quality of the steel as judged by the content of the exit gases. There appears to be a marked similarity between the acid side-blown converter process and the acid open-hearth process in that the reactions are mainly between metal and slag, and the resulting steels have similar properties. A calculated heat balance also shows good comparison with that of the open-hearth process as regards thermal efficiency.

Malleable Foundry Core Sand Practice. J. J. Clark. (American Foundryman, 1946, vol. 10, Aug., pp. 61–69). A detailed illustrated description is given of the foundry-sand practice adopted at the plant of the General Motors Corporation, Saginaw, Michigan. A very high standard of control is maintained, from the digging of the foundry sand to the baking of the cores.

Centrifugal Casting of Metals in Germany. (British Intelligence Objectives Sub-Committee, F.I.A.T. Final Report No. 81: H.M. Stationery Office). A report on German methods of centrifugal casting is presented. The methods and machines for centrifugally casting iron pipes—a very large quantity of which was made by this process—were those in common use before 1939. The manufacture of cylinder liners and barrels for petrol engines was on about the same plane of technical development as in the United States and Great Britain. The use of the thin silica sand lining for the mould was new to the inspectors and may be an important development. The casting of steel gun barrels was highly developed, and the use of the thin sand mould (clean silica sand spun in the mould just before casting) may be a real advance in the casting of heavy tubing. The vertical method did not seem to be as good as the horizontal one. The thin sand-lined mould was also used very successfully for the horizontal spinning of high-chromium steel tubing.

Coneygre Foundry. V. C. Faulkner. (Foundry Trade Journal, 1946, vol. 80, Nov. 7, pp. 231–236). A detailed illustrated description is given of the present scheme of working at the historic Coneygre Foundry, which is said to have been started by Dud Dudley more than 300 years ago. The works are now highly mechanized and in some respects are in advance of their contemporaries.

Steel Foundry Developments. (Iron and Steel, 1946, vol. 19, Oct., pp. 549–550). A brief account is given of the reconstruction work in progress at the steel foundry of William Beardmore & Co., Ltd., Glasgow. The height of the

main building is being increased so that more powerful cranes can be accommodated. On completion it will be possible to handle castings up to 120 tons.

Navy Yard Revamps Foundry. P. Dwyer. (Foundry, 1946, vol. 74, Sept., pp. 79–82, 182–184; Oct., pp. 112–115, 195–202). An illustrated description is given of the plant and operations at the foundry of the Norfolk Naval Shipyard, Portsmouth, Virginia. The plant was extended and modernized during the periods 1914–1918 and 1940–1945.

Exothermic Materials. C. G. Lutts, J. P. Hickey, and M. Bock. (American Foundryman, 1946, vol. 10, Aug., pp. 71–76). An investigation is reported into the use of exothermic reaction mixtures for producing directional solidification in castings of medium-carbon steel, corrosion-resistant steel, and monel metal. Illustrations show the drastic reductions in shrinkage in castings brought about by the addition of powdered mixtures of metal oxides and aluminium in the risers. The metal resulting from the reaction has to be of the same composition as the casting itself, since the additions of powder may amount to as much as 25% of the combined weight of casting and riser, the usual amount being about 15%.

Elimination of Casting Defects. G. Johnstone, jun. (Foundry, 1946, vol. 74, Aug., pp. 76–78, 164–170; Sept., pp. 92–95, 210–215). Improvements to control in grey-iron foundries are discussed and the steps taken to decrease the rejections of large steam-engine cylinder castings are described. Details are given of the pattern and flask equipment for casting the cylinders horizontally. The second part of the paper deals with the classification of defects and the functions of a well-organized inspection department.

Acceptance Standards for Castings. L. W. Ball. (Aircraft Production, 1946, vol. 8, Jan., pp. 3–6). A critical examination is made of the possibility of the use of radiography and X-ray micrography in the assessment of quality in castings. Test bars can indicate only to a limited extent the quality of the metal in the different parts of a casting. Radiography and X-ray micrographs reveal in a unique way all discontinuities, but as some of these may be of relatively little significance, the problem arises of agreeing upon standards acceptable to producers and consumers. Critical areas have to be specified and standard radiographs and X-ray micrographs chosen for these areas which show the degree of discontinuity which is to be tolerated. This can be achieved by statistical analysis.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat-Treating Furnaces. V. Paschkis. (American Foundryman, 1946, vol. 10, Aug., pp. 81–86). The classification of furnaces for the heat-treatment of castings into types according to mechanical design, source of heat, and method of heat transfer is explained. The factors to be considered in selecting a furnace are discussed, with particular reference to economy and the quality of the product.

Induction Heating Applied to Steel Gears. T. H. Gray. (Materials and Methods, 1946, vol. 24, Oct., pp. 915–918). The application of induction-heating to the hardening of gear teeth is described, with illustrated examples. The methods of contour-hardening and through-hardening are compared from the standpoint of the mechanical properties and stress distribution. A process combining carburizing and induction-heating has been successfully applied to gears requiring high strength and wear resistance. The power available places a limitation on the simultaneous hardening of all the teeth on a gear, and a method of individual tooth treatment has been devised. The ultimate solution to the problem of heat-treating gears is said to be over-all contour-hardening by induction, without supplementary treatments such as carburizing.

Radio Frequency Heating in the Metallurgical Field. J. G. Reed. (Electrical Engineer and Merchandiser, 1946, vol. 23, July 15, pp. 121–129). This article covers briefly the history and general application of radio-frequency heating in the metallurgical field, with special reference to surface hardening and brazing. A 20-kW. induction heater recently installed at the Ordnance Factory, Maribyrnong (Australia), is described in detail, and operating data obtained during experimental production work are given, together with graphs showing the empirical data required for the estimation of equipment ratings.

Induction Heating with Electronic Generators. (Steel, 1946, vol. 119, Sept. 30, pp. 84, 87). Illustrated descriptions are given of two induction-type electronic power generators installed at Camden, New Jersey. They have outputs of 2 and 15 kW. respectively, and convert the commercial 60-cycle supply to a frequency of 400,000 cycles/sec.

Some Aspects of Nitriding. S. A. J. Sage. (Metallurgia, 1946, vol. 34, Oct., pp. 299–303). Typical defects occurring in nitrided articles are described with illustrations. Variations in

finished components can occur even when great efforts are made to follow the established nitriding practice.

The Nitriding of High-speed Steel Tools in Salt Baths. E. F. Watson. (Machinery, 1946, vol. 69, Nov. 21, p. 662). A general account is given of the practice adopted for the nitriding of high-speed steel tools in salt baths.

Hardening and Tipping Tools in a Carbon Muffle. E. F. Watson. (Machinery, 1946, vol. 69, Oct. 24, pp. 517–519). A description is given of the equipment and procedure for hardening high-speed steel tools in a small carbon muffle. The process is free from decarburization, scale, or excessive carburization. The same furnace can be used for copper-brazing tips on to tool shanks.

Modern Methods in the Heat-Treatment of Steel. E. R. Mertz. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 637–642). The construction of time-temperature-transformation diagrams (**S**-curves) and their use in applying the interrupted-quench processes for steels are described. Martempering, austempering, and cyclic annealing are explained in detail. Cyclic annealing is a high-temperature isothermal annealing process intended to produce a predetermined degree of softness, which saves time in the annealing of higher alloy steels. Hardenability curves are used for establishing size limitations for particular heats of steel, and for selecting accurate tempering temperatures.

Heat Treatment and Stabilization of High Carbon Stainless Steels. H. E. Boyer and H. C. Miller. (Materials and Methods, 1946, vol. 24, Sept., pp. 637–641). Investigations of the effects of different heat-treatments on the hardness of a 17%-chromium steel containing 1·00% of carbon and 0·50% of molybdenum are reported. A series of charts show the hardness obtained on quenching in oil, or cooling in air, as well as the effect of subsequent chilling at —120° F. The heat-treatment and stabilizing treatment recommended for this steel is as follows: (1) Heat to 1950° F. in a protective atmosphere; (2) cool in still air to room temperature; (3) chill in cooled air to —120° F.; and (4) double-temper at 900° F.

Steel Castings and Weldments Residual Stress Relief. C. R. Jelm and S. A. Herres. (American Foundryman, 1946, vol. 10, Sept. pp. 37–47). The literature and data on the relief of residual stresses by heat-treatment, are reviewed. Three methods of determining the effects of stress-relief annealing are discussed: (1) Measurement of movement of an actual part during machining, before and after annealing; (2) measurement of the elastic extension or bend remaining after the annealing of specimens prestressed in a jig; (3) the determination of a stress-time curve by loading a tensile-test specimen at an elevated temperature and reducing the load to maintain the gauge length at a constant extension. The relief of stresses during annealing is due to the combined action of the reduction in yield strength of the material at high temperatures and creep under decreasing stress. Analysis of the available data indicates that the amount of relief of residual stress brought about by heat-treating in the range 750–1300° F. is independent of the type, composition, and yield strength of the steel. The higher the original residual stresses, the higher will be the stresses remaining after a given heat-treatment. The permissible residual stress and the dimensional stability on machining vary considerably, and should influence the heat-treatment specifications. A compromise is often necessary between maximum stress relief and optimum physical properties as influenced by tempering, precipitation hardening, and similar effects. A list of 71 references is appended.

FORGING, STAMPING, DRAWING AND PRESSING

Theory of Forging Hammers and Their Foundations. W. C. Andrews and J. H. A. Crockett. ((Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1945–46, vol. 89, pp. 53–100). A report is presented of a large-scale investigation into the behaviour of hammers, their foundations, the ground, and the adjoining buildings. The investigation produced a true understanding of the action of hammers and led to the development of a theory of design which is presented in a form suitable for application by the practising engineer.

A Heavy Fabricated Hydraulic Press. (Engineer, 1946, vol. 182, Nov. 15, pp. 438–439). An illustrated description is given of a large vertical down-stroking hydraulic press installed at Rodley, Leeds. The base, press-head, and moving table are of welded construction, and the latter is actuated by three hydraulic rams which can exert a combined load of 500 tons at a rate of 15 in. per min.

Designing, Drafting and Using Press Tools. C. W. Hinman. (Steel Processing, 1946, vol. 32, Aug., pp. 515–518). A detailed illustrated description is given of the design and use of press tools for the production of **E** and **I** laminations

for transformer coils, from rectangular sheets of silicon-steel strip. The die design, evolved during twelve years of experience, gives the very high degree of accuracy required in the finished parts. As many as 4,000 blanks/min. can be cut.

Pressure Forming. T. W. Elkington. (Sheet Metal Industries, 1946, vol. 23, Oct., pp. 1943–1950). The design of pressure-forming tools is discussed and several examples which serve to explain the use of pressure on shallow heavy-gauge formed parts are described.

Dies for Cold Headers. H. H. Palmer. (Materials and Methods, 1946, vol. 24, Sept., pp. 646–650). The various machining, grinding, lapping, and heat-treatment operations involved in making dies for cold-heading machines are described in detail.

Warm-Worked Casing—A New Oil Country Product. J. J. Dunn. (Iron and Steel Engineer, 1946, vol. 23, July, pp. 51–57, 77). The problem of improving the resistance of casing for deep oil wells to external pressure is considered by reviewing the results of earlier investigations, in particular T. M. Jasper and J. W. W. Sullivan's work (*see* Journ. I. and S.I., 1932, No. I., p. 652), and more recent research by the National Tube Company. The results of "collapse-pressure" tests on steel tubes which had been hot-reduced to produce work-hardening are presented and discussed. From these results a manufacturing procedure was developed in which the final reduction in diameter and wall-thickness was carried out at a temperature between the blue brittle range and the lower critical temperature so as to produce a controlled amount of work-hardening.

1,500,000,000 Needles. (Machinery, 1946, vol. 69, Nov. 14, pp. 615–624). An illustrated description is given of the methods employed by Needle Industries, Studley, in attaining an annual output of 1,500,000,000 needles with a labour force of 500 workers. Most operations are highly mechanized, but the need for very skilled operators remains, as is shown in the detailed accounts of the processes of wire-drawing, cutting, straightening, pointing, "skimming" (or descaling of the centre portion of the wire where the eyes are to be formed), stamping, and eyeing.

ROLLING-MILL PRACTICE

Fluctuations of the Distribution of Torque between Rolling-Mill Spindles. E. A. W. Hoff. (Journal of the Iron and Steel Institute, 1947, vol. 155, Jan., pp. 51–54). The paper describes fluctuations of torque found when the torques acting in the two connecting spindles of a two-high rolling mill were recorded separately and independently during the operation of the mill. Some of these fluctuations were periodical and in step with the roll revolutions. These are attributed to mechanical imperfections of the driving gear. Other non-periodic fluctuations are thought to be caused by the surface condition of the rolled stock. In an Appendix it is shown that none of the fluctuations found could have originated from the universal joints of the spindles.

Leather Packings for Hydraulic Roll Jacks. R. W. Justice. (Iron and Steel Engineer, 1946, vol. 23, Sept., pp. 82–84). Details are given of a new design for the leather packing for hydraulic roll balance jacks.

German Wire Rod Rolling Industry. (British Intelligence Objectives Sub-Committee, 1945, Final Report No. 625 : H.M. Stationery Office). Reports on visits to seven German wire-rod mills are presented. The only modern mill inspected was that built by Siemag at the Hermann Göring Works, Salzgitter. This plant was almost completely erected, but had not commenced production.

Hot Rolled Strip Mills. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 581 : H.M. Stationery Office). This report contains data on the mill stands, drives, and capacities of eight German mills for hot-rolling strip.

Statistical Control in Manufacturing Steel Strips and Tin Plate. M. M. Armstrong. (Iron and Steel Engineer, 1946, vol. 23, July, pp. 69–77). The data required for the effective statistical control of the production of tinplate, black sheets, and blue sheets are enumerated and classified, and examples are given of the forms and charts used in a control system which resulted in an improvement in the quality and quantity of production at an American sheet mill.

Protecting Mill Equipment with Hard-Facing. G. E. Wilson. (Iron and Steel, 1946, vol. 23, Sept., pp. 63–66). Examples of maintenance work on rolling-mill equipment are described in which surfaces subject to severe wear are coated by welding on a layer of a nickel-base alloy called "Hastelloy CHF." The examples include refacing shear blades, entry and delivery guides, dies, and shafts.

WELDING AND FLAME-CUTTING

Shipyard Layout and Technique for Welded Construction. H. H. Hagan. (Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1945–46, vol. 89, pp. 325–349). A detailed description is given of the changes in the layout of a shipyard and of the reorganization of traditional methods and personnel which were effected over a period as the change from riveted to welded construction was made. The experience gained in the welding of ships and some future improvements to the shipyard are also discussed.

Pressure Vessel Production. Welding, 1946, vol. 14, Oct., pp. 446–459). A detailed illustrated description is given of the recently built welding shop of Messrs. G. A. Harvey & Co. (London) Ltd., which is specially designed for the manufacture of large pressure vessels to Lloyd's Class 1 specification.

Electronic Control. B. G. Higgins. (Aircraft Production, 1946, vol. 8, Apr., pp. 155–159). Descriptions are given of the construction and method of operation of electronic control equipment for resistance welding. The types of control illustrated are those in which the welding transformer primary current is directly and electronically controlled by an ignition contactor for spot-welding, and by a "synchronous chain commutator" for seam-welding.

Photoelectric Controlled Welding. (Steel, 1946, vol. 119, Sept. 30, p. 72). A brief illustrated description is given of a multiple spot-welding machine in use in a Chicago railway wagon works. The operation is controlled by a photo-electric cell, which causes the completion of the electric circuit of 48 stationary electrodes at the required moment as the work moves underneath them.

Resistance Welding. H. E. Lardge. (Aircraft Production, 1946, vol. 8, Mar., pp. 107–113). A general review is made of the results obtained in the application of resistance welding to materials for constructing combustion chambers. Metallurgical factors and welding technique involved in the spot, stitch, and seam welding of annealed 18/8 austenitic stainless steel, Inconel (nickel 80%, chromium 14%, iron 6%), and an 80/20 nickel-chromium alloy are discussed. The author gives welding data and the results of physical tests, and micro-sections of welds made in sheet material varying in thickness from 16 to 26 S.W.G. To reduce the amount of distortion these materials can be welded under water since they are all corrosion-resisting and non-quench-hardening, and two methods of doing this are outlined. The importance of the inspection of welds is emphasized.

Modern Resistance Welding. W. Bernard. (Australian Welding Institute: Australasian Engineer, 1946, Sept. 7, pp. 58–63). The processes and equipment for spot, projection, seam, and flash-butt welding are described and cost data for a number of applications are given.

Resistance Welding. I. H. Hogg. (British Engineering Export Journal, 1946, vol. 29, Oct., pp. 442–449). The principal types of modern British resistance-welding equipments are reviewed, with illustrations, and several applications of them are indicated.

Resistance Welding with Storage Battery Power. J. D. Gordon. (American Society of Mechanical Engineers: Steel Processing, 1946, vol. 32, Aug., pp. 497–501). The use of power from storage batteries for the production of resistance welds is described in detail. A new type of battery has been developed for this purpose, with a water-cooling device which allows a very high charging rate to be attained. By a suitable arrangement of batteries in series and parallel, any combination of voltage and current can be obtained, the welding practice being the same as for the conventional A.-C. type of welding unit. A heavy-duty contact controller capable of making and breaking 200 times/min. a circuit carrying 40,000 amp. is used in conjunction with a simple electronic timer. Successful welds have been made in materials ranging from very thin gauge mild and stainless steels to $\frac{3}{16}$-in. aluminium sections. Welding using storage batteries is consistent and economical in power because of the constancy of the voltage and the absence of eddy-current losses.

Bronze Welding of Castings. A. V. Bell. (New Zealand Engineering, 1946, vol. 1, Aug. 10, pp. 416–418). The technique for bronze-welding to repair iron castings is described. The positions at which to apply preheating treatment to prevent the cracking of castings of various shapes after completion of the weld are shown in a series of drawings.

CLEANING AND PICKLING

Soft-Grit Blasting. E. C. Lathrop and S. I. Oronovsky. (Compressed Air Magazine: Steel, 1946, vol. 119, July 22, pp. 102–108). The use of waste cereal materials instead of metal shot for shot-blasting is discussed. Ground corncobs

and ground rice husks entrained in compressed air have proved to be very suitable for removing carbon deposits, dirt, paint, and varnish from metal surfaces without pitting the metal.

Preparation of Metals for Painting. R. E. Gwyther. (Electrochemical Society, American Chemical Society, and American Institute of Chemical Engineers, Joint Symposium: Steel, 1946, vol. 119, Oct. 14, pp. 158–164). A brief account is given of the cleaning of metal surfaces by chemical spraying and sand blasting, and of the phosphate treatment of iron and steel before painting.

PROTECTIVE COATINGS

Function of Specifications in Electroplating. C. E. Huessner, C. O. Durbin, and D. W. Munro. (Electrochemical Society, American Chemical Society, and American Institute of Chemical Engineers, Joint Symposium: Steel, 1946, vol. 119, Oct. 14, pp. 164–168). Details are given of some of the specifications of the Chrysler organization for electroplated coatings on steel.

Hard Chromium Plate and Its Uses. J. M. Hosdowich. (Materials and Methods, 1946, vol. 24, Oct., pp. 596–600). The term "hard chromium plate" is shown to be a misnomer for "thick chromium plate," *i.e.*, a layer of chromium much thicker than that used for purposes of decoration and without the usual underlying coating of relatively soft nickel. Chromium plate owes its increasing industrial use to a unique combination of hardness, corrosion resistance, and low coefficient of friction. A comprehensive list of many of the more important applications is given; particular reference is made to the plating of gauges, cutting tools, dies, rolls, and drums.

Measurement of Embrittlement during Chromium and Cadmium Electroplating and the Nature of Recovery of Plated Articles. C. A. Zapffe and M. Eleanor Haslem. (American Society for Metals, Nov., 1946, Preprint No. 29). The data reported in this paper, which is the fourth of a series exploring the nature of hydrogen embrittlement, provide quantitative measurement (by means of the constant-rate single-bend test) of the embrittlement produced in annealed and in cold-drawn 17%-chromium 1%-carbon stainless steel wire during electroplating with chromium and cadmium respectively. Curves are given showing the course of embrittlement with increasing plating time, and comparing the actions of chromium, cadmium, and hydrogen in the hydrogenation of steel. Hydrogen embrittlement resulting from chromium plating is much more severe than that produced by straight cathodic pickling under the same conditions of temperature and current density. Cadmium plating has a similar effect, but is not quite as severe as chromium plating in causing embrittlement. The recovery from embrittlement in the ageing process is shown to take place in three stages. For chromium plating, but not for cadmium plating, a sufficiently heavy coating can superimpose its mechanical properties, particularly brittleness, upon those of the steel. Aqueous solutions are found to be more successful than oil or dry argon as media for ageing.

German Production of Galvanized, Hot-Tinned and Enamelled Hollow-Ware. (British Intelligence Objectives Sub-Committee, 1946, Report No. 793: H.M. Stationery Office). Reports are submitted on visits to eleven German firms representative of the German galvanizing, tinning, and enamelling industry. The machines used were, on the whole, identical to those used in the United Kingdom. Worthy of interest was the Bonderizing of blanks to be used for deep-drawing; this enabled the number of intermediate annealings to be reduced.

Production of Cast-Iron Porcelain-Enamelled Baths in Germany. R. L. Hunter. (British Intelligence Objectives Sub-Committee, Final Report No. 437: Foundry Trade Journal, 1946, vol. 80, Oct. 17, pp. 169–172). This report on German methods of making porcelain-enamelled baths contains accounts of the processes used at a number of works not covered in the previous Report No. 344 (*see* Journ. I. and S.I., 1946, No. II, p. 77A).

German Tinplate Industry. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 610: H.M. Stationery Office). Reports are presented on the plant and processes used at eleven German works manufacturing tinplate.

Recent Developments in the Use of Electrolytic Tinplate and Phosphated Blackplate. W. G. Cass. (Sheet Metal Industries, 1946, vol. 23, Oct., pp. 1917–1918). Investigations and developments in the United States and Germany on methods of reducing tin consumption by the electrolytic coating of steel strip and by using phosphated blackplate for canning foods are reviewed.

Some New Aspects of the Protection of Steel by Tin and Tin Alloy Coatings. E. S. Hedges and W. E. Hoare. (Metal Treatment, 1946, vol. 13, Autumn Issue, pp. 197–205). The main results obtained at the Tin Research Institute on improvements to the corrosion resistance of tin coatings on steel are reported. The process of

treating tinplate in an alkaline phosphate-chromate solution described by R. Kerr (*see* Journ. I. and S. I., 1946, No. II., p. 76A) is discussed, and a method (developed by F. V. Jones) of determining whether tinplate has been "filmed" is described. The properties of deposits of tin-zinc alloy coatings (this process has been described by R. M. Angles, *see* Journ. I and S. I., 1946, No. I., p. 80A) are also considered. Two electro-deposited tin-zinc coatings, containing respectively 80% and 50% of tin, are available for the protection of steel.

Better Tinplate—The "Protecta-tin" Process. (Tin and Its Uses, 1946, Oct., p. 4). The method of applying an invisible protective film to tinplate described by R. Kerr (*see* Journ. I. and S. I., 1946, No. II., p. 76A) is referred to. It is known as the "Protecta-tin" process. A test for determining whether a plate has been film coated is described. It is only necessary to immerse the sample for 2 min. in boiling yellow ammonium-sulphide solution, when a filmed plate will remain bright and an unfilmed one will be blackened.

Electro-Depositing Tin-Zinc. J. W. Cuthbertson. (Tin and Its Uses, 1946, Oct., p. 13). The simultaneous plating of tin and zinc on steel and the properties of coatings of 80/20 and 50/50 tin-zinc alloys are discussed and recommendations on the optimum plating conditions are made. The process has already been described by R. M. Angles (*see* Journ. I. and S. I., 1946, No. I., p. 80A).

Cadmium Plate and Passivated Cadmium Plate Coatings. E. E. Halls. (Metallurgia, 1946, vol. 34, Oct., pp. 295–297). Experimental details and results are given of an investigation designed to compare the corrosion-resistant properties of coatings on mild steel, brass, and copper, of normal cadmium plate and cadmium plate passivated by immersing in a chromate solution. The latter proved much superior, the increased protection afforded by it being out of all proportion to the small effort and cost involved in its application.

Clad Steel Processing Equipment for Chemical and Allied Industries. E. C. Gosnell. (Electrochemical Society, American Chemical Society, and American Institute of Chemical Engineers, Joint Symposium: Steel, 1946, vol. 119, Oct. 14, pp. 156–158). A survey is given of the application of clad steels in the chemical industry.

Action of Antifouling Paints. B. H. Ketchum and J. D. Ferry. (Industrial and Engineering Chemistry, vol. 38, Sept., pp. 931–936). An anti-fouling paint containing rosin or other acid resins in the matrix loses both toxic and matrix simultaneously when immersed in the sea. The loss of matrix is shown to be the result of the dissolution of acidic resin in the slightly alkaline sea water. A paint of this sort maintains a uniform and adequate leaching rate because the dissolving matrix gradually exposes stores of toxic which were originally deep within the paint films. The substitution of neutral resins, which are insoluble in sea water, for rosin or other resins which are insoluble, may decrease or destroy the ability of the paint to maintain adequate leaching rates. A theoretical description of the simultaneous dissolution of toxic and matrix is presented, and the effects of surface residues of insoluble matrix components on the dissolution of the paint are discussed. The toxicity of a paint which operates by this mechanism depends on the loading of the toxic ingredient and the solution rate of the matrix. The ability to adjust these two variables independently permits great flexibility in formulating a paint to have a desired leaching rate.

POWDER METALLURGY

Densities of Iron Powder Compacts. R. Steinitz. (Powder Metallurgy Bulletin, 1946, vol. 1, Sept., pp. 70–71). Increasing the density of parts made from iron powders improves the physical and magnetic properties, but these improvements incur higher production costs. It is therefore desirable to press a part to the lowest possible density at which it will still perform satisfactorily. A large range of densities (from 96% to 60%) can easily be produced by using different powders and pressures. For the convenient selection of the necessary procedure, a table is presented for shop use, listing powders and pressures for small intervals in final density.

Formation and Transformation Studies of Iron-Carbon Powder Alloys. J. F. Kahles. (American Society for Metals, Nov., 1946, Preprint No. 13). The results of an investigation into the properties of mixed iron and carbon powders show that very pure steels may be prepared by pack-carburizing compressed "carbonyl-L" iron powder. The austenite transformation characteristics of these powder products do not differ markedly from steels made from the liquid state. A time-temperature-transformation diagram for a "powder-metallurgy" steel with 0·87% of carbon is reproduced, and some trends in the methods of carburization of compressed powdered iron are indicated.

PROPERTIES AND TESTS

The Rapid Determination of the Elastic Limit in Steels. J. R. Cornelius. (Machinery, 1946, vol. 69, Nov. 7, pp. 590–591). A method for the accurate determination of the elastic limit is described. The specimen is inserted in the extensometer unit complete with the Cornelius electronic comparator. The application of a load causes the specimen to become stressed, and a reduction in the natural frequency of the electronic unit occurs because of the electronic disturbance in the specimen. This disturbance continues at a constant ratio throughout the elastic range. The approach to the elastic limit is indicated by the flattening out of the frequency curve and the precise position of the elastic limit is shown by the sudden rise in the curve, showing that the frequency has ceased to decrease and begun to increase.

Poisson's Ratio of Some Structural Alloys for Large Strains. A. H. Stang, H. Greenspan, and S. B. Newman. (Journal of Research of the National Bureau of Standards, 1946, vol. 37, Oct., pp. 211–221). A description is given of determinations of Poisson's ratio for aluminium-alloy sheet, chromium–molybdenum steel plate, and low-carbon steel plate. The results are presented as graphs of Poisson's ratio against percentage axial strain, *i.e.*, the percentage increase in length of the original gauge length.

Plastic Strain in Isotropic Strain-Hardening Material. H. W. Swift. (Motor Industry Research Association : Engineering, 1946, vol. 162, Oct. 18, pp. 381–384). In this mathematical paper the relationships between stress and plastic strain in isotropic strain-hardening material are developed.

White and Gray Irons—Ductility and Elasticity. R. A. Flinn and H. J. Chapin. (American Foundry, 1946, vol. 10, Aug., pp. 47–58). Measurements of the elastic and plastic strain in tension were made on a large number of white and grey cast irons having different microstructures. Compression, hardness, creep, and impact tests were also carried out. Greater strength and ductility were obtained in the low-carbon irons with acicular structures than in the high-carbon irons with tempered martensite. The austenitic grey irons containing 14–30% of nickel and 2–3% of chromium were the most ductile irons tested. Microhardness tests on the different constituents showed that the carbides of the alloying elements were not harder than iron carbide. The hardness of the carbides of the austenitic grey irons was practically the same as that of the white irons, despite the small areas available for measurement and the soft matrix. The test data are presented in tables and the stress-strain curves are plotted and compared. Examples are given which show that these curves are of much greater value than the tensile strength alone when selecting an iron for a particular purpose.

Proving Rings for Calibrating Testing Machines. B. L. Wilson, D. R. Tate, and G. Borkowski. (National Bureau of Standards, 1946, Circular No. C454). A description is given of the proving ring which was developed at the National Bureau of Standards to provide an accurate portable load-measuring device for calibrating testing machines. Methods are described for calibrating proving rings by dead weights for loads up to 110,000 lb. and by means of other calibrated proving rings for higher loads. The specifications for proving rings are given in an appendix. Rings complying with these specifications were subjected to tests to determine the errors introduced by variations in conditions of use, and these showed that, when reasonable care was exercised, the errors are very small compared with the accepted tolerance of $\pm$ 1%.

Photo-Elastic Apparatus, Technique, and Materials. A. W. Hendry. (Journal of the Institution of Civil Engineers, 1946, vol. 27, Nov., pp. 85–91). A detailed description is given of the apparatus and technique employed for photo-elastic testing in the Engineering Departments of Aberdeen University. Photo-elastic analysis is a method of determining the stresses in machines and structures in cases where mathematical treatment is not easily applied. The results of a number of experiments on the mechanical and optical properties of the plastic "Catalin" are given.

The Behaviour of the Surface Layers of Alloy Steel under Static and Dynamic Tensile-Compressive Stresses. A. Schaal. (Zeitschrift für Metallkunde, 1944, vol. 36, July, pp. 153–163). An investigation is reported in which X-ray determinations were made of the stresses in the surface layers of a low-alloy chromium–molybdenum steel during static tension, compression, and pull-push tests, as well as during dynamic fatigue tests. The results are presented in tables and by graphs. The tests showed that flow begins when the stress determined by X-rays exceeds a limiting value which, in this investigation with cobalt radiation, amounted under tension to about 44 kg./sq. mm., and under compression to about 55 kg./sq. mm.

Summary Report on the Joint E.E.I.-A.E.I.C. Investigation of Graphitization of Piping. S. L. Hoyt, R. D. Williams, and A. M. Hall. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 571–577). *See* Journ. I. and S. I., 1946, No. II., p. 78A.

Studies on Susceptibility of Casting Steels to Graphitization. J. J. Kanter. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 581–586). An investigation is reported on the susceptibility to graphitization and stability at high temperature of a number of alloy cast steels suitable for welding. The rectangular test bars were cast in a special form, and a single bead was deposited on each. After a stress-relieving heat-treatment at 1200° F., sections of the bars were aged for periods of up to 6,000 hr. at 1025° F. to obtain an indication of the susceptibility to graphitization. The results, illustrated in photomicrographs, show that aluminium additions to carbon-molybdenum steels cause susceptibility. Coalescence of the carbide appears to precede its breakdown to graphite. No evidence of graphitization was found in the steels containing chromium (from 0·43% to 0·70%), and this is considered to be due to the resistance of the carbide to spheroidization.

Comparative Graphitization of Some Low-Carbon Steels with and without Molybdenum and Chromium. G. V. Smith, S. H. Brambir, and W. G. Benz. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 589–595). Details are given of the graphitization occurring in steels containing 0·5% of molybdenum and up to 1·20% of chromium when they were heated at 1025° F. for periods up to 3,000 hr. The tests showed that at least 0·5% of chromium is necessary to prevent graphitization, in a 0·5% molybdenum steel, and that more than 0·5% of chromium prevents any graphitization, whatever may have been the treatment of the steel beforehand. The addition of varying amounts of aluminium to heats of steels containing 0·1–0·2% of carbon revealed that more than 1 lb. of aluminium per ton of steel is necessary before graphitization takes place. The temperature-time cycles occurring in welding were simulated in molybdenum steels. The maximum amount of graphitization was found in the zone affected by the welding heat which had reached a temperature of 1400° F. Annealing at 1300° F. for 4 hr. after welding, but before service, prevented graphitization in samples of steam piping.

Further Observations of Graphitization in Aluminium-Killed Carbon–Molybdenum Steel Steam Piping. R. W. Emerson and M. Morrow. (Transactions of the American Society for Mechanical Engineers, 1946, vol. 68, Aug., pp. 597–607). A description is given of the discovery of a form of graphitization in steam pipes not connected with the heat-affected zone adjacent to a weld. The name "slip-plane" graphitization has been given to this phenomenon, as it is found to occur along slip planes where local yielding or plastic deformation has taken place. The degree of graphitization varies markedly around the periphery of the pipe, and can be seen with the naked eye after machining. The mechanism of formation of both types of graphitization is thought to be the same, namely, the solution of the carbide phase in ferrite, followed by the precipitation of graphite. Evidence is produced to show how this precipitation in the case of slip-plane graphitization is nucleated by stress, and it is postulated that tessellated stresses may cause nucleation in the regions adjacent to welds.

Graphitization in Some Cast Steels. A. J. Smith, J. B. Urban, and J. W. Bolton. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 609–620). *See* Journ. I. and S. I., 1946, No. II., p. 57A.

Influence of Heat-Treatment upon the Susceptibility to Graphitization of High-Aluminium-Deoxidized Carbon–Molybdenum Steel. F. Eberle. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 625–630). *See* Journ. I. and S. I., 1946, No. II., p. 57A.

METALLOGRAPHY

The Necessity for Close Contact between Metallurgy and Physics. E. Orowan. (Sheet Metal Industries, 1946, vol. 23, Oct., pp. 1915–1916, 1919). The metallurgist learns, during his university career, just enough physics to understand the contemporary routine methods of metallurgy, but not enough for what will be routine methods in five or ten years' time, and not enough to be fully qualified for the work on the development of these methods. The best method of establishing the necessary contact between metallurgy and physics is by giving metallurgists as much fundamental physical training as is necessary under modern conditions, and resorting to the physicist only in special cases. Some modifications to university courses in metallurgy are suggested and the views of younger metallurgists are put forward.

Some Problems of the Metallic State. Sir Lawrence Bragg. (Transactions of the North-East Coast Institution of Engineers and Shipbuilders, 1945–46, vol. 62, pp. 25–34). *See* Journ. I. and S. I., 1946, No. I., p. 12A.

The Electron Microscope—Its Use in Metallography and in Studying the Condition of Surfaces. G. Dupouy. (Metal Treatment, 1946, vol. 13, Autumn Issue, pp. 153–168, 205). A very detailed description is given of the first electron microscope to be constructed in France; it is in the author's laboratory at the Faculty of Science of Toulouse. The emission, transmission, and reflection processes by which the electron microscope can be used to study surface conditions are discussed and their usefulness compared. In conclusion, examples of the use of the instrument for examining (*a*) the structure of incandescent surfaces, (*b*) the allotropic states of metals, (*c*) corrosion, (*d*) the texture of metals and alloys, and (*e*) miscellaneous surfaces, are described with many illustrations.

Applications of Recent X-Ray Inspection Equipment. J. L. Bach. (Machinery, 1946, vol. 69, Nov. 21, pp. 663–665). Illustrations are given of the application in industrial concerns in the United States of very high voltage X-ray units. A new and compact 1,000,000-V. installation mounted on an overhead crane enables radiographs of 8-in. steel plates to be taken in 16 min., whereas a less powerful unit formerly required 60 hr. The X-ray examination of very thick sections, such as welds in pressure vessels and crankshafts, which used to require very long exposures, is now easily carried out with a 1,000,000-V. equipment.

Investigation of German Researches on Fine Structure of Metals with Especial Reference to X-Ray Diffraction Techniques. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 826). Visits to German metallographic research institutes and to three makers of X-ray diffraction equipment are reported. The following developments were noted: (*a*) The magnetic focussing X-ray tube, (*b*) the combined X-ray and electron diffraction tube, (*c*) the use of Geiger counters for rapid registry of X-ray diffraction lines, (*d*) the reduction of exposure times by special focussing arrangements, (*e*) complete diffraction units were available in a notably compact form, and (*f*) the behaviour of metallic structures under stress was the subject of intense study.

X-Ray Diffraction as an Analytical Tool. D. Goodman. (Iron Age, 1946, vol. 158, Sept. 19, pp. 55–58). Work done in the X-ray laboratory of the Armour Research Foundation of the Illinois Institute of Technology is reported. The examples of X-ray diffraction studies which are quoted include the determination of the proportions of austenite and ferrite in cold-worked stainless steel.

A Note on the Mode of Occurrence of Tellurium in Cast Iron. H. Morrogh. (Journal of the Iron and Steel Institute, 1947, vol. 155, Jan., pp. 21–23). The unique features of the influence of tellurium in cast iron are emphasized. By metallographic means employing the polarizing microscope it is shown that in the presence of an excess of manganese over that required to neutralize the sulphur, tellurium forms manganese ditelluride. With no manganese or with insufficient manganese to balance the sulphur, iron monotelluride is formed. Various aggregates of manganese sulphide, manganese ditelluride, iron sulphide, and iron telluride are described.

CORROSION

Factors in Corrosion Control. H. H. Uhlig. (Electrochemical Society, American Chemical Society, and American Institute of Chemical Engineers, Joint Symposium: Steel, 1946, vol. 119, Oct. 14, pp. 108–109, 144–150). Seven methods by which the rate of corrosion of a metal may be reduced are discussed. They are: (1) Cathodic protection; (2) metallic coating; (3) inorganic and organic coating; (4) passivation and inhibition; (5) alteration of the environment, *e.g.*, oxygen removal; (6) metal purification; and (7) alloying. The properties of the metal and its structure are inherent factors in the corrosion process, whether or not physically protective films form on the surface.

Cathodic Protection as a Corrosion Control Method Applied to Steel Surfaces Submerged in Water. L. P. Sudrabin. (Corrosion, 1946, vol. 2, Oct., pp. 175–187). The principles of cathodic protection are explained and the factors affecting the design and the material for the anode to be used to protect steel surfaces submerged in different waters, and methods of determining the current density are discussed. A number of examples of the successful application of cathodic protection are cited.

Magnesium Anodes for the Cathodic Protection of Underground Structures. H. A. Robinson. (Corrosion, 1946, vol. 2, Oct., pp. 199–218).

Laboratory and field investigations of factors affecting the efficiency of magnesium anodes for the cathodic protection of underground structures are reported. The conclusions derived from laboratory work were: (1) The cell-magnesium anode is not likely to perform efficiently except at high current densities; (2) magnesium–aluminium and magnesium–aluminium–zinc alloys perform more efficiently than cell-magnesium at the low current densities normally obtaining for field installations; (3) of the alloys tested, 91/6/3 magnesium–aluminium–zinc had the best over-all performance characteristics; (4) magnesium anodes operate more efficiently in sulphate than in chloride electrolytes; and (5) the most uniform distribution of the attack on the anode is obtained with saturated solutions of either calcium sulphate or magnesium sulphite as the electrolyte. The current efficiencies observed with cell-magnesium ranged from 10% to 35% (the average of test results was about 27%); no correlation of efficiency with current density could be observed with cell-magnesium anodes, but with magnesium alloy anodes the efficiency tended to increase with the current density.

Problems of Automotive Cooling System Corrosion Inhibition. D. H. Green and R. A. Willihnganz. (Steel, 1946, vol. 119, Oct. 14, p. 168). The factors influencing corrosion in water-cooling systems are enumerated. Two types of inhibition have been found to be effective in such systems, namely, alkaline buffering materials such as amines and borates, and film-forming materials such as oils, phosphates, chromates, nitrites, and silicates. The best results are obtained with a combination of the two types.

The Causes and Prevention of Caustic Embrittlement in Steam Boilers. W. Murray and W. F. Gerrard. (Fuel Economy Review, 1946, vol. 25, pp. 48–52). A general account is given of the phenomenon of caustic embrittlement in steel plates. The conditions essential for this type of inter-crystalline corrosion are known to be the presence of caustic soda in solution, strain beyond the elastic limit in the steel, and a minimum temperature of 85–100° C. The usual method of preventing caustic embrittlement is the use of inhibitors in the water in contact with the steel. A theory is put forward to explain the action of sodium sulphate as an inhibitor.

The Susceptibility of Low-Alloy Carbon Steel to Stress Corrosion. Å. Junghem. (Teknisk Tidskrift, 1946, vol. 76, Nov. 16, pp. 1141–1149). (In Swedish). Examples of the stress-corrosion cracking of boiler plate, pipe connections and vessels used for chemical processes are cited and methods of testing the susceptibility of steel specimens in the form of bars and plates are described. A number of British, American, and German investigations of the phenomenon are reviewed.

Quantitative Evaluation of Intergranular Corrosion of 18-8 Ti. F. J. Phillips. (American Society for Metals, Nov., 1946, Preprint No. 6). A survey is made of the detection, cause, and methods of eliminating intergranular corrosion in 18/8 stainless steels. The usual additions of the stabilizing elements, titanium and columbium, do not always prevent corrosion. This is attributed to the absence of sufficient titanium carbide to prevent the formation of chromium carbide during subsequent heat-treatment. A quantitative method for predicting intergranular corrosion in titanium-stabilized 18/8 steel has been developed. An explanation is given for the corrosion of 18/8 steels in which the titanium content exceeded the stoichiometric ratio of four times the carbon content. The quantitative method is based on studies of microstructure and chemical composition and is thought to be applicable to other grades of stainless steel.

BOOK REVIEWS

Brillouin, L. "*Wave Propagation in Periodic Structures. Electric Filters and Crystal Lattices.*" First edition. 8vo, pp. xii + 247. New York, 1946: McGraw-Hill Book Co. Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 20*s.*)

This volume incorporates a variety of problems linked by a common mathematical background, extending from electrical engineering to electromagnetism and wave mechanics of the spinning electron. All problems deal with periodic structures of various kinds, which invariably, whether they are electric lines or crystal lattices, behave like band-pass filters. Explanations applying to electric filters, rest-rays, anomalous optical reflection, and selective reflection of X-rays or electrons from a crystal, are covered.

Catton, J. L. "*Combustion and Modern Coal-Burning Equipment.*" 8vo, pp. vi + 121.

Illustrated. London, 1946: Sir Isaac Pitman and Sons, Ltd. (Price 10*s*. 6*d*.)

A review of modern practice in combustion control with a description of the mechanical appliances and devices used in the economic consumption of solid fuel for industrial and domestic uses.

CHUTE, G. M. "*Electronics in Industry.*" First Edition, 8vo, pp. xii + 461. Illustrated. New York, 1946: McGraw-Hill Book Co. Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 25*s*.)

This book is intended for the reader with little technical training, and describes a wide variety of electronic equipment used in industry.

KNORR, K. E. "*Tin under Control.*" 8vo, pp. xi + 314. California, 1945: Food Research Institute, Stanford University. (Price 16*s*. 6*d*.)

This book surveys the history of tin between the two World Wars. It examines the revolutionary changes brought about by the last war and, on this basis, attempts to estimate the post-war status and problems of the tin industry. Particular emphasis is placed on international control arrangements for purposes of price stabilization and on preventing the price-depressing consequences of surplus production.

LEYSON, B. W. "*Careers in the Steel Industry.*" 8vo, pp. 191. Illustrated. New York, 1945: E. P. Dutton and Co., Inc. (Price 15*s*.)

The author describes the making of steel through its various stages and draws attention to the opportunities that exist for employment in the American steel industry.

WALKER, R. C. "*Electronic Equipment and Accessories.*" Second Edition, 8vo, pp. viii + 391. Illustrated. London, 1946: George Newnes, Ltd. (Price 25*s*.)

The author explains the chief applications and the special forms of electronic equipment. In the early chapters the fundamental characteristics of the thermionic valve are dealt with, and also its various applications. Separate chapters are devoted to gas-filled valves, light-sensitive devices, and the applications of light cells, while the principles of the cathodic ray tube and the methods of using it are described. Information is also given concerning miscellaneous electronic devices, small switchgear, time delay devices, and circuit accessories.

WAMPLER, R. H. "*Modern Organic Finishes. Their Application to Industrial Products.*" 8vo, pp. xii + 452. Illustrated. Brooklyn, 1946: Chemical Publishing Co., Inc. (Price 51*s*.)

Descriptions are given of modern finishing materials, together with particulars of equipment for their application, drying, and conveying.

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CARSLAW, H. S. "*Introduction to the Mathematical Theory of the Conduction of Heat in Solids.*" Second Edition, 8vo, pp. 268. New York, 1945: Dover Publications. (Price 21*s*.)

CATTON, J. L. "*Combustion and Modern Coal-Burning Equipment.*" London: Sir Isaac Pitman and Sons, Ltd. (Price 10*s*. 6*d*.)

HUME-ROTHERY, W. "*Atomic Theory for Students of Metallurgy.*" Institute of Metals Monographs and Report Series. No. 3. 8vo, pp. viii + 286. Illustrated. London 1946: The Institute of Metals.

IRON AND STEEL INSTITUTE. Special Report No. 32. "*Third Report on Refractory Materials.*" Being a Report by the Joint Refractories Research Committee of the British Iron and Steel Research Association and the British Refractories Research Association. 8vo, pp. v + 387. Illustrated. London, 1946: The Institute. (Price 16*s*.)

IRON AND STEEL INSTITUTE. SPECIAL REPORT NO. 37. "*The Influence of Port Design on Open-Hearth Furnace Flames.*" By J. H. Chesters and M. W. Thring. 4to, pp. vii + 187. Illustrated. London, 1946: The Institute. (Price 16*s*.)

SANDY, A. H. "*Cutting Tools for Engineers.*" Revised Ed. 8vo, pp. x + 129. Illustrated. London, 1946: Crosby, Lockwood and Son, Ltd. (Price 5*s*.)

SIMONDS, H. R. and A. BERGMAN. "*Finishing Metal Products.*" Second Edition. New York: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 20*s*.)

SIMONS, E. N. "*Saws and Sawing Machinery.*" 8vo, pp. vii + 224. Illustrated. London, 1946: Sir Isaac Pitman and Sons, Ltd. (Price 15*s*.)

SOKOLNIKOFF, I. S., and R. D. SPECHT. "*Mathematical Theory of Elasticity.*" New York: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 22*s*. 6*d*.)

SWANSEA AND DISTRICT METALLURGICAL SOCIETY. "*Controlled Atmospheres.*" By Ivor Jenkins. (General Meeting, February 17, 1945.) 8vo, pp. 27. Briton Ferry.

WAMPLER, R. H. "*Modern Organic Finishes. Their Application to Industrial Products.*" 8vo, pp. xii + 452. Illustrated. Brooklyn, N.Y.: Chemical Publishing Co. (Price 51*s*.)

How true is Steel?

STEEL is proverbially true. But not naturally so, for in the 'skin' of every steel ingot there are bound to be certain impurities or 'seams.' When it is destined for high quality products, these faults are removed before the ingot is finally rolled into bar, girder or sheet. The slow, old-fashioned way was to cut out the imperfections with hammer and chisel. The modern way is to cut them out with oxygen by a process known as 'hand deseaming' or 'desurfacing.' In fact, some steel works use mechanical means for the same process, by which the oxygen treatment is applied to two or even all four sides of a steel billet or bloom at one 'pass' or operation and at 200 ft. a minute . . . a speed undreamt of before oxygen desurfacing was introduced. This is another of the many ways in which The British Oxygen Company Ltd. helps to speed up production.

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